Mercury in San Francisco Bay

Total Maximum Daily Load (TMDL) Project Report

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Introduction

Section 303(d) of the Clean Water Act requires states to compile a list of "impaired" water bodies that do not meet water quality standards. All San Francisco Bay segments are impaired because mercury adversely impacts established beneficial uses, including sport fishing, preservation of rare and endangered species, and wildlife habitat. This report contains Regional Board staff analyses and findings pertaining to mercury impairment of San Francisco Bay and staff recommendations for an implementation plan to address the impairment. Regional Board staff will draft a Basin Plan Amendment, which, if adopted by the Regional Board, will establish a Total Maximum Daily Load (TMDL) for mercury in San Francisco Bay, including related implementation actions.

Problem Statement

Mercury concentrations in San Francisco Bay fish are high enough to threaten human health and the beneficial use of sport fishing. The California Office of Environmental Health Hazard Assessment has issued an interim fish consumption advisory for San Francisco Bay. In addition, mercury concentrations in some bird eggs harvested from the shore of San Francisco Bay are high enough to account for abnormally high rates of eggs failing to hatch; therefore, mercury threatens wildlife and rare and endangered species. Because controllable water quality factors cause detrimental mercury concentrations in sediment, aquatic organisms, wildlife, and humans, the narrative water quality objective for bioaccumulative substances is not met in San Francisco Bay.

Mass Budget Approach

Using a simple mass budget model facilitates the analysis of mercury sources to San Francisco Bay. Relying on such a model allows the identification and prioritization of reasonable solutions without over-interpreting limited available data. Although a mass budget box model underlies much of the analysis presented in this report, Section 8, Implementation Plan, explains plans to refine the model as more information about mercury transport, fate, and effects becomes available.

Source Analysis

About 1,220 kg of mercury enters San Francisco Bay each year. The sources of mercury in San Francisco Bay include bed erosion (about 460 kilograms per year [kg/yr]), the Central Valley watershed (about 440 kg/yr), urban storm water runoff (about 160 kg/yr), the Guadalupe River watershed (about 92 kg/yr), direct atmospheric deposition (about 27 kg/yr), non-urban storm water runoff (about 25 kg/yr), and wastewater discharges (about 19 kg/yr). San Francisco Bay loses mercury as sediment is transported to the ocean through the Golden Gate (about 1,400 kg/yr), mercury evaporates from the bay surface (about 190 kg/yr), and dredged material is removed and disposed of (about 150 kg/yr, net).

Numeric Targets

To protect sport fishing and human health, the concentration of mercury in fish tissue must be reduced by about 40% to 0.2 parts per million (ppm). To protect wildlife and rare and endangered species, the concentration of mercury in bird eggs must be reduced by about 50% to 0.5 ppm. To achieve the fish tissue and bird egg targets and to attain water quality standards, the concentration of mercury in sediment must be reduced by about 50%; the median concentration of mercury in sediment should be 0.2 ppm. These proposed targets are consistent with antidegradation policies.

Linkage Analysis

Efforts to reduce mercury loads will help achieve targets and attain water quality standards because the targets are linked to the sources. Most mercury in San Francisco Bay is bound to sediment; therefore, reducing loads from mercury sources will reduce sediment mercury concentrations. Methylmercury accumulation in aquatic organisms depends on sediment mercury concentrations, methylmercury production, and the structure of the food web. Reductions in sediment mercury concentrations are assumed to result in proportional reductions in fish tissue and bird egg mercury concentrations. Reducing net methylmercury production will further reduce mercury exposures. Assuming that the amount of mercury in San Francisco Bay needs to be reduced by about 50% to meet the proposed targets, the assimilative capacity of the bay is about 32,000 kilograms.

Allocations

To reach the proposed sediment target and attain water quality standards, the proposed load and wasteload allocations are as follows: bed erosion, 220 kg/yr; Central Valley watershed, 330 kg/yr; urban storm water runoff, 82 kg/yr; Guadalupe River watershed (mining legacy), 2 kg/yr; atmospheric deposition, 27 kg/yr; non-urban storm water, 25 kg/yr; and wastewater, 19 kg/yr. This proposed allocation scheme is based on the assumption that mercury from all sources is similarly available to be converted to methylmercury and taken up into the food web. By implementing the proposed allocations, the average sediment mercury concentration in the bay will likely drop from about 0.44 ppm to about 0.15 ppm, reaching the target of 0.2 ppm after at least 120 years. Conservative assumptions used to develop the proposed numeric targets and allocations provide an implicit margin of safety.

Implementation Plan

The implementation plan has four objectives: (1) reduce total mercury loads to the bay, (2) reduce methylmercury production, (3) perform monitoring and focused studies to track progress and improve technical understanding of the system, and (4) encourage actions that address multiple contaminants. An adaptive implementation approach is proposed, which means taking immediate actions based on available information and defining a process by which to incorporate technical information as the plan is adapted in the future.

The Central Valley Regional Board is developing mercury TMDLs expected to reduce mercury loads from Central Valley watersheds sufficiently to be able to ensure that sediment from Central Valley rivers eventually meets the sediment target of 0.2 ppm. Likewise, the mercury load that is a legacy of mercury mining in the Guadalupe River watershed will be reduced to about 2 kilograms over the next 20 years. A separate TMDL effort for this watershed will be the primary regulatory driver for actions to achieve this reduction.

Urban storm water loads are expected to be reduced from about 160 kg/yr to about 80 kg/yr over a course of 20 years. This will be achieved through a combination of source control and targeted sediment removal and storm water treatment. Atmospheric deposition is thought to contribute about 27 kg/yr directly to the bay surface and about 55 kg/yr through deposition on the local watershed and then conveyance to the bay. Available data suggest that this source is not easily controlled because the majority of atmospheric mercury emissions take place in Asia.

Municipal wastewater dischargers, as a group, will be held to current mercury loads. Exceedance of proposed concentration-based triggers will compel investigation of cause and consideration of enhanced treatment. Existing information is insufficient to estimate loads for sources like local mines and bay margin contaminated sites. The proposed plan requires investigation of these sites to determine their impacts and reasonable next steps to reduce loads, if necessary.

Wetlands are not a source of new mercury, but they are important to the cycling of methylmercury in the bay. The plan encourages and supports studies to develop ways in which wetlands can be designed and managed so as to minimize the production of methylmercury. If wetlands are being restored and come under Regional Board jurisdiction, the plan is to require a demonstration that the project does not result in a net increase in the production of methylmercury.

As these actions are underway, TMDL implementation will also include working with the California Office of Environmental Health Hazard Assessment and the California Department of Health Services to manage the human health risk from consumption of mercury-contaminated bay fish.

These immediate actions are commensurate with available data and information. The implementation plan also includes monitoring to assess the effectiveness of these actions and progress toward meeting proposed targets. In addition, the strategy calls for reviewing information obtained through ongoing scientific studies every five years and revising the TMDL and implementation plan as appropriate.

1. Introduction

This Project Report presents San Francisco Bay Regional Water Quality Control Regional Board (Regional Board) staff recommendations pertaining to establishing a Total Maximum Daily Load (TMDL) and implementation plan for mercury in San Francisco Bay. It contains results of staff analyses of mercury impairment and sources, and recommended mercury load reduction allocations and implementation actions. The report is a milestone in the Regional Board's water quality attainment strategy to resolve mercury impairment of San Francisco Bay.

Background

The Clean Water Act requires California to adopt and enforce water quality standards to protect San Francisco Bay. The *Water Quality Control Plan, San Francisco Bay Basin (Region 2)* (Basin Plan) delineates these standards by identifying beneficial uses of the bay, numeric and narrative water quality objectives to protect those uses, and provisions to enhance and protect existing water quality (SFBRWQCB 1995). Section 303(d) of the Clean Water Act requires states to compile a list of "impaired" water bodies that do not meet water quality standards. All segments of San Francisco Bay appear on the list because mercury impairs the bay's established beneficial uses, including sport fishing, preservation of rare and endangered species, and wildlife habitat (SWRCB 2003). For purposes of this report, "San Francisco Bay" refers to the following water bodies, as shown in Figure 1.1:

- Sacramento/San Joaquin River Delta
- Suisun Bay
- Carquinez Strait
- San Pablo Bay
- Richardson Bay
- Central San Francisco Bay
- Lower San Francisco Bay
- South San Francisco Bay (including the Lower South Bay)

This report also addresses the following mercury-impaired water bodies that exist within the water bodies listed above:

- Castro Cove (part of San Pablo Bay)
- Oakland Inner Harbor (part of Central San Francisco Bay)
- San Leandro Bay (part of Central San Francisco Bay)

Section 303(d) of the Clean Water Act requires states to develop plans to attain water quality standards in impaired water bodies. In December 1998, Regional Board staff prepared a preliminary report on watershed management of mercury in the Northern Reach of San Francisco Bay (north of the San Francisco-Oakland Bay Bridge)

FIGURE 1.1: Map of San Francisco Bay Estuary
Eight unique segments of San Francisco Bay appear on the 303(d) list of impaired water bodies: Sacramento/San Joaquin River Delta, Suisun Bay, Carquinez Strait, San Pablo Bay, Richardson Bay, Central San Francisco Bay, Lower San Francisco Bay, and South San Francisco Bay. Three additional mercury-impaired water bodies exist within these segments: Castro Cove, Oakland Inner Harbor, and San Leandro Bay.

(SFBRWQCB 1998a). In June 2000, Regional Board staff completed a report on watershed management of mercury in all of San Francisco Bay. That report was developed with stakeholder input and summarized the information available regarding mercury in the bay (SFBRWQCB 2000). This Project Report follows up on the earlier reports. It reflects comments received from interested parties over the years and new information obtained since June 2000.

Report Organization

The process for establishing a TMDL includes compiling and considering available data and information and appropriate analyses relevant to defining the impairment problem, identifying sources, and allocating responsibility for actions to resolve the impairment. This Project Report is organized into the following sections that reflect the key elements of the TMDL process:

1. **Introduction**—provides background on this report and the TMDL process.
2. **Problem Statement**—describes the basis for concluding that mercury impairs San Francisco Bay, including the water quality standards not being met.
3. **Mass Budget Approach**—describes some of the basic concepts and assumptions underlying the analysis.
4. **Source Assessment**—identifies and quantifies the various contributions of San Francisco Bay mercury sources.
5. **Numeric Targets**—expresses the condition desired for San Francisco Bay by proposing numeric targets, which, if met, would ensure attainment of water quality standards.
6. **Linkage Analysis**—describes the relationship between mercury sources and the proposed targets, and estimates the bay's capacity to assimilate mercury while still meeting water quality standards.
7. **Allocations**—proposes wasteload allocations for permitted mercury sources and load allocations for other sources, and describes the margin of safety afforded by the analysis.
8. **Implementation Plan**—proposes mercury pollution prevention and control actions necessary to reach targets, specifies monitoring mechanisms to evaluate progress, and describes how new information will be gathered and considered as it becomes available.
9. **References**—lists all the information sources cited and relied upon to prepare this report.

Next Steps

As the next step in the TMDL process, Regional Board staff will draft a Basin Plan Amendment to incorporate into the Basin Plan the findings set forth here regarding mercury impairment and the proposed implementation plan. Staff will then present the draft Basin Plan Amendment to the Regional Board for consideration and possible adoption. If adopted, the State Water Resources Control Board will consider the Basin Plan Amendment, and if approved, the U.S. Environmental Protection Agency will consider this TMDL. Stakeholder comments and concerns will continue to be considered at key milestones throughout the process.

Key Points

- Section 303(d) of the Clean Water Act requires states to compile a list of “impaired” water bodies that do not meet water quality standards.
- San Francisco Bay is impaired because mercury adversely impacts established beneficial uses, including sport fishing, preservation of rare and endangered species, and wildlife habitat.
- This report contains Regional Board staff analyses and findings pertaining to mercury impairment of San Francisco Bay and staff recommendations for an implementation plan to address the impairment.
- Regional Board staff will draft a Basin Plan Amendment, which, if adopted by the Regional Board, will establish the TMDL for mercury in San Francisco Bay, including related implementation actions.

2. Problem Statement

Mercury is a persistent, bioaccumulative, toxic metal that does not degrade in the environment. It exists in elemental, inorganic, and organic forms. Natural processes transform mercury between the elemental and inorganic forms, and between the inorganic and organic forms. The organic form, methylmercury, is the most toxic. Small aquatic organisms take in methylmercury, allowing it to enter the food web. As methylmercury moves through the food web, it accumulates and concentrates in organisms at the top of the food web. High levels of mercury have been found in San Francisco Bay fish, including the fish humans and wildlife eat (SFEI 2003a; U.S. EPA 1997a). This report explains how mercury levels in San Francisco Bay exceed water quality objectives and impair beneficial uses, such as sport fishing, wildlife habitat, and preservation of rare and endangered species.

Fish Consumption and Human Health

In humans, mercury is neurotoxic, affecting the brain and spinal cord, and interfering with nerve function. Pregnant women and nursing mothers can pass mercury to their fetuses and infants through the placenta and breast milk. In children, particularly those under age six, mercury can decrease brain size, delay physical development, impair mental abilities, cause abnormal muscle tone, and result in coordination problems. Substantial mercury exposure is also associated with birth defects and infant mortality. Adults exposed to mercury may experience abnormal sensations in their hands and feet, tiredness, or blurred vision. Higher levels of mercury exposure can impair hearing and speech. Long-term exposure can damage the kidneys (D'Itri 1991; Davies 1991; COEHHA 1997; U.S. DHHS 1999; U.S. EPA 1997b).

In humans, the principal route for mercury exposure is through the consumption of mercury-containing fish (U.S. EPA 2001). San Francisco Bay is used for recreational sport fishing and subsistence fishing. Because of elevated mercury levels in bay fish, the California Office of Environmental Health Hazard Assessment issued the following interim fish consumption advisory for San Francisco Bay (COEHHA 1999):

- Adults should consume no more than two meals per month of sport fish from the bay, including sturgeon and striped bass.
- Adults should not eat striped bass over 35 inches long.
- Pregnant women, nursing mothers, and children under age six should limit their consumption of sport fish to one meal per month.
- Pregnant women, nursing mothers, and children under age six should not eat striped bass over 27 inches long or shark over 24 inches long.

The interim advisory does not apply to salmon, anchovies, herring, and smelt caught in the bay; fish caught in the delta or ocean; or commercial fish (San Francisco Bay supports commercial bait shrimp, herring, and Dungeness crab fisheries).

Since the human health risks associated with eating San Francisco Bay fish warrant a fish consumption advisory, mercury in San Francisco Bay impairs the beneficial use of sport fishing.

Wildlife and Rare and Endangered Species

Mercury poses potential hazards to birds, mammals, and other wildlife. Birds and mammals that consume fish and other aquatic organisms can be exposed to significant quantities of mercury. In birds, mercury can adversely affect survival. It can affect cell development and reproductive success, and cause developmental problems in the young. It can cause reduced feeding, weight loss, lack of coordination, hyperactivity and hypoactivity, and liver and kidney damage. In mammals, mercury can reduce speed and agility, making it more difficult to obtain food and avoid predation (U.S. EPA 1997c). The embryos of birds and other vertebrates are more sensitive to mercury exposure than adults (Wiener et al., in press).

Bird eggs representing species that consume bay fish and other aquatic organisms have been harvested from the shoreline of San Francisco Bay. They have higher mercury concentrations than eggs from the same species in other regions of the country (CDFG 2002; Davis et al., in press; Schwarzbach et al. 2000). Mercury concentrations in eggs from the San Francisco Bay region occur at concentrations that have been shown to cause reproductive harm in laboratory tests (Fimreite 1971; Heinz 1979). These mercury concentrations may account for unusually high numbers of San Francisco Bay bird eggs failing to hatch (CDFG 2002; Davis et al., in press; Schwarzbach et al. 2000). Mercury toxicity appears to be one of the primary causes of mortality in eggs of the endangered California clapper rail, which eats aquatic organisms. Because of the small foraging range of the California clapper rail, its eggs are particularly vulnerable to local methylmercury levels. The high bird egg mercury concentrations potentially threaten birds and other wildlife, including rare and endangered species. Consequently, mercury impairs the beneficial uses of wildlife habitat and protection of rare and endangered species.

Compliance with Water Quality Objectives

Federal Clean Water Act regulations and the Basin Plan contain water quality standards. These standards identify beneficial uses of the bay and numeric and narrative water quality objectives to protect those uses. They also include provisions to enhance and protect existing water quality (SFBRWQCB 1995). Three water quality objectives apply to mercury in San Francisco Bay:

- ***Basin Plan Numeric Objective***. The Basin Plan limits total mercury in water to a 4-day average concentration of 0.025 micrograms per liter (µg/l, parts per billion) north of the Dumbarton Bridge.

- ***California Toxics Rule Numeric Objective***. Regulations implementing the Federal Clean Water Act limit total mercury in water to 0.051 µg/l throughout San Francisco Bay (Code of Federal Regulations, Title 40, Section 131.38).

- ***Basin Plan Narrative Objective***. The Basin Plan limits bioaccumulative substances as follows:

> Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered.

To monitor pollutant concentrations in water, sediment, and fish and shellfish tissue, the San Francisco Estuary Institute administers the San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP). Monitoring began in 1993. San Francisco Bay water samples are collected three times a year to capture seasonal variability. Two dozen sampling stations are located throughout the bay and at its major tributaries. More than 100 individual chemical parameters are measured, including mercury concentration.

Unlike the numeric Basin Plan objective for mercury, RMP data do not represent four-day averages. The samples are collected over periods of less than one hour (SFEI 2001a). Figure 2.1 shows total mercury concentrations in water reported by the RMP for 1993 through 1999. Measured mercury levels in San Francisco Bay exceed 0.025 µg/l roughly 21% of the time, although four-day average concentrations are believed to exceed the numeric Basin Plan objective infrequently, as discussed in Section 4, Numeric Targets. However, mercury levels in San Francisco Bay exceed the narrative water quality objective for bioaccumulative substance because mercury accumulates in sediment, fish, and other aquatic organisms at detrimental levels, as described in the fish consumption and wildlife discussions above, and some of the water quality factors responsible for these conditions are controllable, as discussed in Section 3, Source Assessment; Section 7, Allocations; and Section 8, Implementation Plan.

Key Points

- Mercury concentrations in San Francisco Bay fish are high enough to threaten human health and the beneficial use of sport fishing. The California Office of Environmental Health Hazard Assessment has issued an interim fish consumption advisory for San Francisco Bay.
- Mercury concentrations in some bird eggs harvested from the shore of San Francisco Bay are high enough to account for abnormally high rates of eggs failing to hatch; therefore, mercury threatens wildlife and rare and endangered species.
- Because controllable water quality factors cause detrimental mercury concentrations in sediment, aquatic organisms, wildlife, and humans, the narrative water quality objective for bioaccumulative substances is not met in San Francisco Bay.

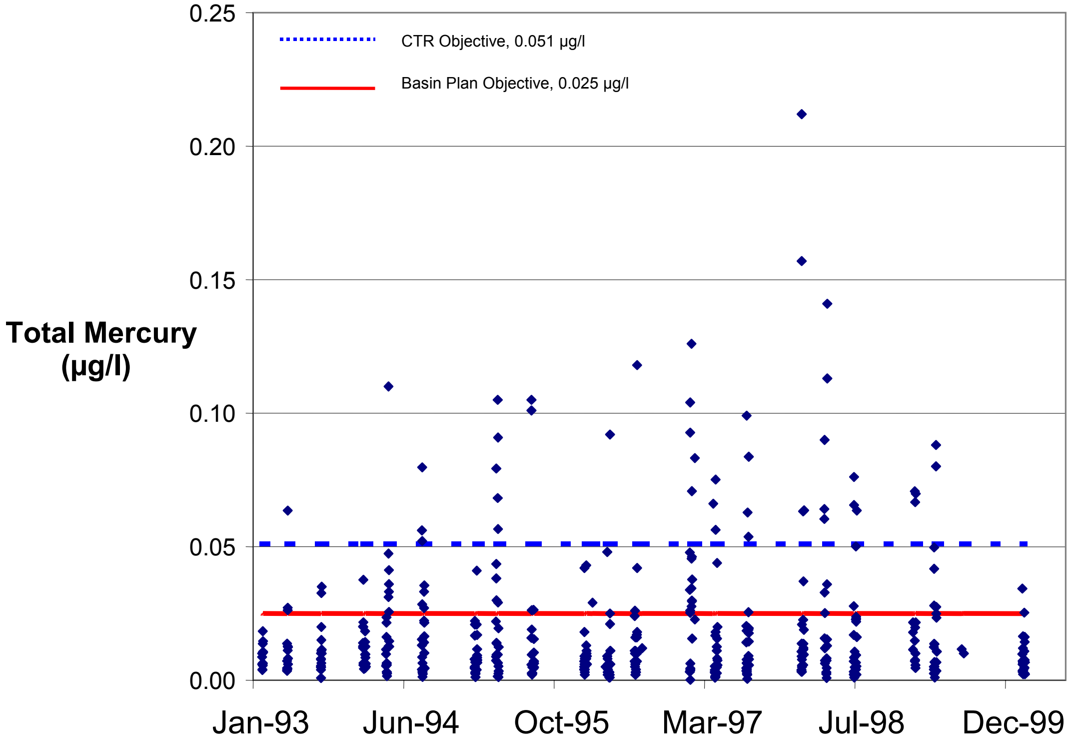

FIGURE 2.1: Total Mercury Concentrations in San Francisco Bay Water
Total mercury concentrations have been measured in San Francisco Bay water annually from 1993 through 2000. Short-term (less than one hour) mercury concentrations often exceed the Basin Plan objective that applies to 4-day averages (SFEI 2003b). The number of samples shown is 465. Two extreme values from the Guadalupe River in 1997 and 1998 are not shown because they are off the scale of the figure.

3. Mass Budget Approach

A Workable Approach to a Complex Situation

San Francisco Bay is the largest estuary in western North America. Located at the mouth of the Sacramento/San Joaquin River Delta, its watershed encompasses about 60,000 square miles, or 40% of California (STB et al. 2000). Water and sediment circulation patterns are especially complex as a result of the bay's elongated shape, the large volume of water that passes through its northern reach, its narrow connection to the Pacific Ocean at the Golden Gate, and the relatively low freshwater inputs from local tributaries, especially those in South San Francisco Bay.

As described in Section 2, Problem Statement, mercury poses a significant threat to San Francisco Bay wildlife and humans who consume bay fish. Mercury cycling in the environment, coupled with the bay's complexity, make solving the mercury problem a challenge. Studies of mercury transport, fate, and effects in the bay will continue for decades; however, the severity of the environmental threat warrants immediate action. The problem solving approach set forth below is commensurate with available data and adequate to identify and prioritize measures to attain water quality standards.

Mercury fate and transport processes within the bay vary significantly throughout time and space, and available data are insufficient to support detailed analyses without over-interpreting the limited data available. Therefore, this report relies on a simple model to represent San Francisco Bay and some of its basic processes. The advantages of simplicity—the ability to identify and prioritize reasonable actions without over-interpreting available data—outweigh the apparent realism that could be attainable with a more complex model (Harte 1988). The following discussion describes a key assumption that forms the basis for this analytical approach—the bay is a simple box.

One-Box Model

A complex system can be simplified by treating it as a simple "box." A one-box model relates primarily to inputs and outputs, not specific processes that occur within a system. When inputs equal outputs, the amount of material in the box stays the same, and the system is considered to be at steady state. When a system is at steady state, missing information about inputs or outputs can often be derived from available information about inputs and outputs. Box models can also be used to predict how a system may change if inputs or outputs change.

This report uses a steady state one-box model for San Francisco Bay that treats the entire bay as one large container consisting of two compartments, water and active sediment. Active sediment is sediment on the bay floor that is regularly resuspended and deposited as a result of tides, waves, and wind and is located in the biologically active zone of the bay floor. In San Francisco Bay, the active sediment layer is estimated to average approximately 15 centimeters (about six inches) in depth (SFEI 2002d). Buried sediment, or sediment beneath the active layer, is not included in the box, but can enter if sediment in the active layer erodes. Because the active layer is assumed, for model purposes, to have a fixed depth, its mass cannot change. Therefore, the amount of sediment entering the box must roughly equal the amount of sediment leaving the box. In other words, the mass of sediment in the bay is at steady state.

Figure 3.1 identifies sediment sources to San Francisco Bay (inputs to the box). Sediment inputs include erosion of buried sediment and flows from the Central Valley watershed, the Guadalupe River watershed, and other local watersheds (urban and non-urban storm water runoff). Sediment and mercury losses (outputs from the box) include net discharges to the Pacific Ocean through the Golden Gate and dredged material disposal at upland or ocean disposal sites. The sediment inputs are assumed to equal the sediment outputs.

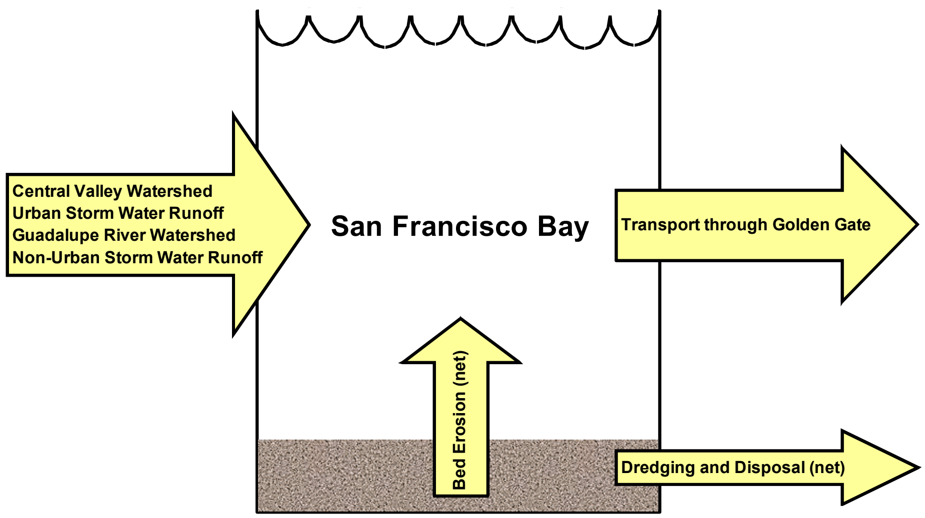

FIGURE 3.1: San Francisco Bay Sediment Sources and Losses
Sediment enters and exits San Francisco Bay. For purposes of this report, the simple one-box model assumes sediment is at steady state (i.e., sediment loads and losses are equal).

The sediment steady state assumption does not imply that mercury is at steady state. Figure 3.2 identifies mercury sources (inputs to the box), which include all the sediment sources, plus atmospheric deposition and wastewater discharges. Mercury losses (outputs from the box) include all the sediment losses, plus evaporation from the bay's surface. (The term "evaporation" is used here to refer to any loss to the atmosphere.)

The assumptions associated with the one-box model affect the conclusions expressed in the report's various sections. Section 4, Source Assessment, describes estimated mercury loads for each source and loss category (inputs and outputs). The sediment steady state assumption is used to fill critical information gaps. Section 5, Numeric Targets, proposes a sediment mercury concentration target that defines the goal to be achieved within the box. Section 6, Linkage Analysis, explores processes most relevant to mercury's fate in

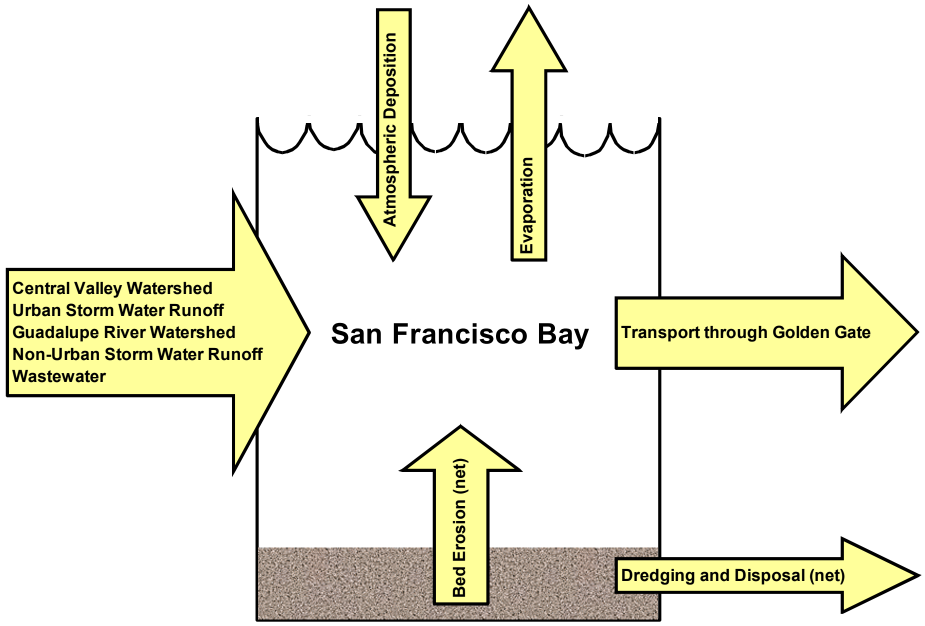

FIGURE 3.2: San Francisco Bay Mercury Sources and Losses
Mercury enters and exits San Francisco Bay. For purposes of this report, the simple one-box model does not assume that mercury is at steady state. Mercury sources and losses are the same as sediment sources and losses, with the addition of wastewater discharges, atmospheric deposition, and evaporation.

the bay and estimates the amount of mercury San Francisco Bay (the box) can assimilate while still meeting water quality standards. Section 7, Allocations, proposes load reductions and, using the one box model, illustrates how San Francisco Bay may respond if the proposed allocations are implemented. Section 8, Implementation Plan, explains how the proposed adaptive management strategy will be used to monitor progress toward meeting the sediment target and to refine the model as more information about mercury transport, fate, and effects becomes available.

Key Points

- Relying on a simple model allows the identification and prioritization of reasonable solutions without over-interpreting limited available data.
- Although a one-box model underlies much of the analysis presented in this report, Section 8, Implementation Plan, explains plans to refine the model as more information about mercury transport, fate, and effects becomes available.

4. Source Assessment

Mercury Sources and Methodology

During the Gold Rush, cinnabar mines in the Central Coast Ranges produced the mercury used to extract gold from the Sierra Nevada foothills (Dorrance 2002; USGS 2000). Later, mercury was used to produce munitions, electronics, and health care and commercial products. Today, the sources of mercury entering San Francisco Bay convey mercury originating from mining legacies and more contemporary mercury uses.

Each source and loss pathway is discussed below. Table 4.1 summarizes each mercury load estimate. Figure 4.1 displays the loads graphically. Mercury and sediment loads vary from year to year; therefore, these estimates are intended to represent long-term averages. The estimates are based on available information; more study may allow refinement in the future.

Most mercury in the water column is particle-bound (see Section 6, Linkage Analysis). Therefore, the magnitude of many mercury sources can be estimated on the basis of sediment loads and mercury concentrations in suspended sediment, as shown in Equation 1.

Equation 1:

$$L_{mercury} = L_{sediment} \times C$$

where:

$L_{mercury}$ = mercury load (kilograms per year, kg/yr)
$L_{sediment}$ = sediment load (million kilograms per year, M kg/yr)
C = mercury concentration in sediment
(milligrams mercury per kilogram dry sediment, or parts per million, ppm)

Calculations and Assumptions

Bed Erosion

The erosion of mercury-enriched sediment from the floor of the bay is estimated to be the largest source of mercury to the bay. From the 1850s through the 1880s, hydraulic mining in the Sierra Nevada involved spraying large volumes of water on hillsides and stripping them of soil, sand, and gravel (USGS 2000). The resulting sediment slurries were directed to sluices lined with mercury, where gold was extracted. Many of the finer mercury and gold particles washed through the sluices and were discharged downstream. Along with mercury, hydraulic mining activities released a substantial mass of sediment, which flowed through the Central Valley to San Francisco Bay. Much of this mercury-

TABLE 4.1: San Francisco Bay Mercury Sources and Losses

	Mercury Load (kg/yr)	Sediment Load (M kg/yr)	Mercury Concentration in Sediment (ppm)
Sources			
Bed Erosion	460	1,100	0.42
Central Valley Watershed	440	1,600	0.26
Urban Storm Water Runoff	160	410	0.38
Guadalupe River Watershed	92	44*	2.1*
Direct Atmospheric Deposition	27	*NA*	*NA*
Non-Urban Storm Water Runoff	25	400	0.06
Wastewater	19	*NA*	*NA*
Total	***1,220***	***3,600***	
Losses			
Transport through Golden Gate	1,400	3,200	0.44
Dredging and Disposal (net)	150	400	0.37
Evaporation	190	0	*NA*
Total	***1,730***	***3,600***	

* The estimates for the Guadalupe River Watershed do not include mercury associated with storm water. The sediment load associated with the Guadalupe River is a subset of the sediment load estimated for urban and non-urban storm water runoff and is not double counted. The sediment mercury concentration in this table reflects only the mercury enrichment due to the Guadalupe River's mining legacy. The actual sediment mercury concentration, including storm water runoff, is about 2.4 ppm.
NA = Not available or not applicable
Note: Most of these mercury and sediment load estimates are rounded to two significant figures. Because calculations were completed prior to rounding, some columns may not add to totals, and in some cases, estimated mercury loads may not exactly equal the product of sediment loads times sediment mercury concentrations.

laden sediment accumulated on the bay floor. After hydraulic mining ended, sediment loads to the bay decreased. Dams constructed in the Central Valley watershed further reduced sediment loads. However, mercury mining in the Central Coast Ranges continued to release mercury into the bay.

Although sediment burial and erosion are ongoing natural processes throughout San Francisco Bay, San Pablo Bay and Suisun Bay studies indicate that more erosion is occurring than burial (USGS 2001a,b). Equivalent studies have not been published for other segments of San Francisco Bay. During the 48 years from 1942 to 1990, Suisun Bay experienced a net loss of about 61,000,000 cubic meters of sediment, averaging a net loss of 1,300,000 cubic meters per year (USGS 2001b). During the 32 years from 1951 to 1983, San Pablo Bay experienced a net loss of about 7,000,000 cubic meters of sediment, averaging a net loss of 220,000 cubic meters per year (about one sixth of what eroded from Suisun Bay each year) (USGS 2001a). Combining these losses from Suisun Bay and San Pablo Bay, the total net loss is about 1,500,000 cubic meters per year. Assuming that the eroding sediment is 50% water and 50% sediment by weight (a common assumption for dredging operations [U.S. ACE 2002b]), there are about 740 kilograms of dry sediment per cubic meter of wet volume (Weast 1981; Elert 2002). The annual net sediment loss is therefore about 1,100 M kg.

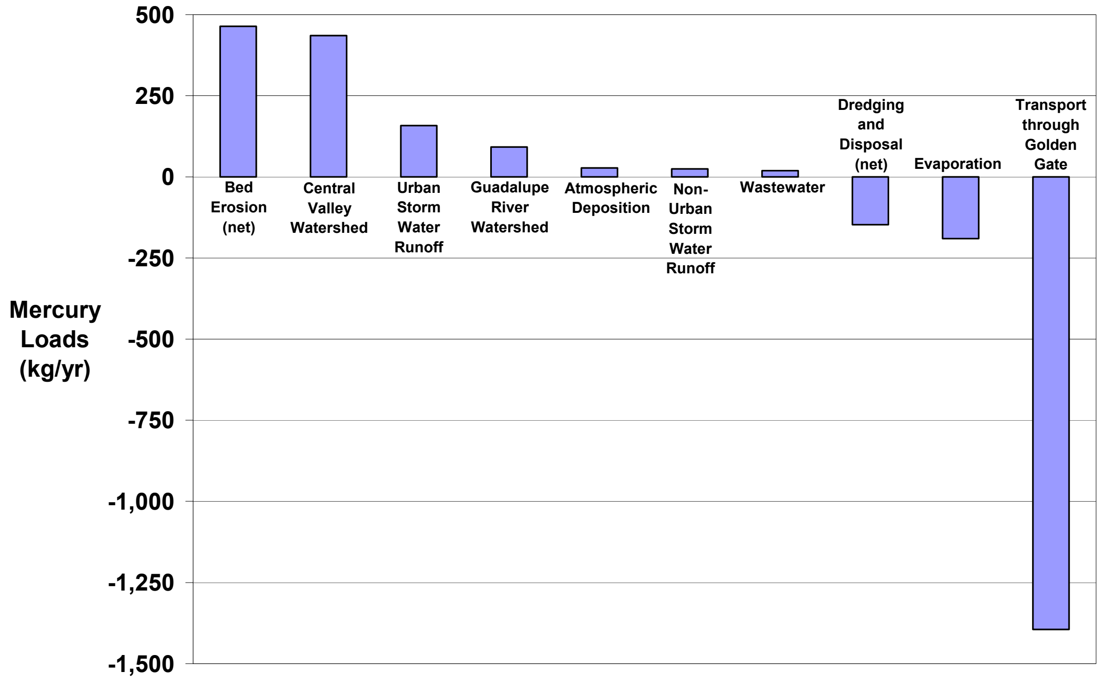

FIGURE 4.1: San Francisco Bay Mercury Source and Loss Loads
The largest sources of mercury are bed erosion and the Central Valley watershed. The greatest loss is transport through the Golden Gate.

As sediment is lost from the floors of San Pablo Bay and Suisun Bay, buried sediment is exposed. This exposed sediment likely contains higher mercury concentrations than the sediment that eroded. Mercury concentrations are available for sediment cores from San Pablo Bay, Grizzly Bay (north of Suisun Bay), and Richardson Bay (Hornberger et al. 1999). Mercury concentrations in buried sediment increase with depth, then decrease substantially below about 1 meter. This gradient is most extreme in Grizzly Bay, as shown in Figure 4.2, which shows mercury concentrations within the top 2 meters of the sample core. The San Pablo Bay and Grizzly Bay sediment cores can be used to estimate the mercury concentration of sediment eroding from the floor of San Pablo Bay and Suisun Bay. (The Richardson Bay core is less likely to be representative of conditions where net bed erosion is known to occur because it is farther away.) The depth-weighted average mercury concentration in the top 1.3 meters of sediment is about 0.42 ppm (SFBRWQCB 2003c). Because the floor of the bay is not eroding evenly (some areas are eroding more than others and burial is occurring at some locations), some newly exposed sediment could contain higher mercury concentrations, and some could contain lower concentrations.

For purposes of this report, mercury loads from bed erosion from bay segments other than Suisun Bay and San Pablo Bay are assumed to be negligible. The U.S. Geological Survey has not yet published estimates of burial and erosion for the bay's southern reach. A separate study of Lower San Francisco Bay and South San Francisco Bay involved collecting sediment cores at depths of 0.7 meters and greater. Sediment mercury

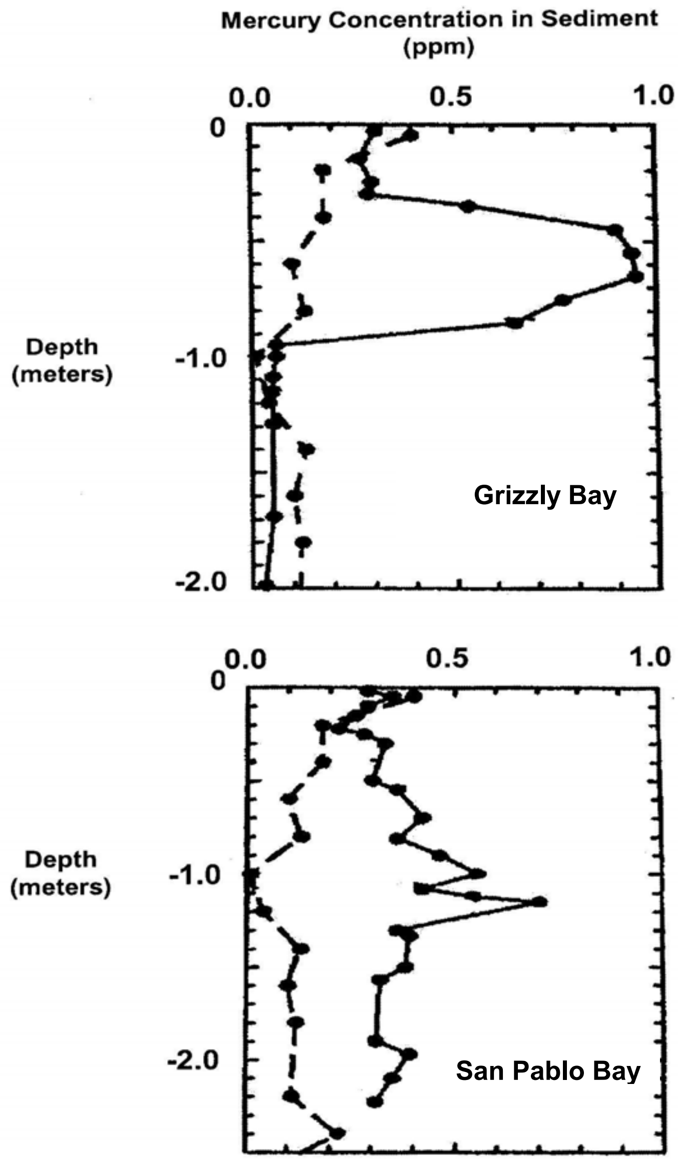

FIGURE 4.2: Mercury Concentrations in Buried Sediment
Solid lines represent mercury concentrations at various depths. Dotted lines represent equivalent concentrations within a reference core collected from Tomales Bay (Hornberger et al. 1999).

concentrations buried at these depths were about 0.1 ppm or less. The mercury concentration pattern in a core from Triangle Marsh (at the southernmost end of the bay, downstream from historic mercury mines) closely resembles that of the Grizzly Bay core shown in Figure 4.2 (SFBRWQCB 2003f). However, because the core was collected from a stable marsh, it is probably not representative of sediment erosion in the bay's southern reach.

Using Equation 1, assuming that eroding sediment from the bay floor contains about 0.42 ppm mercury, and assuming that the net annual sediment loss is about

1,100 M kg/yr, the mercury load associated with newly exposed sediment is roughly 460 kg. This represents about 38% of the total estimated mercury load entering San Francisco Bay. This estimate could be refined if additional sediment cores or more information about how different parts of the bay floor are eroding were to become available in the future.

Central Valley Watershed

San Francisco Bay receives runoff from the Central Valley watershed. The two primary Central Valley rivers, the Sacramento River and the San Joaquin River, drain an area of about 60,000 square miles, equivalent to about 40% of California (STB et al. 2000). These rivers carry mercury-laden sediment from Central Valley mines, urban and non-urban storm water, wastewater, and atmospheric deposition from local and global mercury emissions. The Central Valley watershed is beyond the jurisdiction of the San Francisco Bay Regional Water Quality Control Board. It is under the authority of the Central Valley Regional Water Quality Control Board.

On the basis of suspended sediment concentrations measured near Mallard Island (shown in Figure 1.1) during the six years from October 1994 through September 2000, the amount of sediment entering San Francisco Bay from the Central Valley watershed appears to be about 1,600 M kg/yr, with an uncertainty of ±300 M kg/yr (SFEI 2002a). This closely matches other estimates (Krone 1979; U.S. ACE 1992). The Central Valley mercury load is about 440 kg/yr, with an uncertainty of ±100 kg/yr (SFEI 2002a). This estimate represents about 36% of the bay's total mercury sources. The estimate was derived by extrapolating mercury concentrations measured from March 2000 through October 2001 at X2, the estuary location where the water's salinity is 0.2%. X2 represents the most downstream portion of the river not greatly affected by upstream marine currents; its location moves up and down the estuary, depending on the amount of freshwater flow through the delta. Inserting the estimated sediment and mercury loads into Equation 1, the average concentration of mercury in Central Valley sediment is about 0.26 ppm, with a propagated uncertainty of ±0.075 ppm.

The Central Valley watershed mercury load estimate could be overstated. Recent studies suggest that the mercury load entering the freshwater side of the delta may be smaller than the load leaving at X2. This apparent enrichment may result from the relative lack of sediment data for freshwater entering the delta, available only for 2001 and 2002, when freshwater flows were unusually low (SFEI 2002a). The delta may temporarily retain sediment from year to year, so the amount of sediment entering the delta in any particular year may not equal the amount of sediment leaving the delta. Alternatively, unidentified mercury sources could exist in the delta, or sediment erosion in Suisun Bay (USGS 2001b) could be contributing to mercury observed at X2.

Storm Water

For purposes of this report, "storm water" includes urban and non-urban runoff, which may include flows not directly associated with precipitation (e.g., storm water can include urban irrigation runoff and base flows). Urban runoff includes runoff from developed areas throughout municipalities, industrial sites, and rights of way (e.g., California Department of Transportation highways). The federal Clean Water Act requires National Pollutant Discharge Elimination System (NPDES) permits for storm water discharges. Municipal storm water permits are being phased in over time, beginning with dischargers representing the largest populations. In the Bay Area, the Regional Board issues and administers storm water permits.

Storm water mercury loads can be estimated using Equation 1 (described at the beginning of this section). To determine mercury concentrations in storm water sediment, several urban runoff management agencies collected 113 bed sediment samples from storm water conveyance systems in Contra Costa County, Marin County, San Mateo County, Santa Clara County, and the cities of Fairfield, Suisun, and Vallejo (Kinnetic Laboratories 2002). The study included locations within the jurisdictions of almost all the urban runoff management agencies with National Pollutant Discharge Elimination System (NPDES) permits, listed in Table 4.2.

TABLE 4.2: Urban Runoff Management Programs

Urban Runoff Management Program	NPDES Permit Number
Alameda Countywide Clean Water Program	CAS0029831
Contra Costa Clean Water Program	CA0029912
Fairfield-Suisun Urban Runoff Management Program	CAS612005
Marin County Stormwater Pollution Prevention Program	*
San Mateo County Stormwater Pollution Prevention Program	CA0029921
Santa Clara Valley Urban Runoff Pollution Prevention Program	CAS029718
Vallejo Sanitation and Flood Control District	CAS612006

* The Marin County Stormwater Pollution Prevention Program is not currently subject to an NPDES permit because fewer people live in Marin County cities than in the jurisdictions of the other urban runoff management programs.

The sample locations were selected to represent storm water conduits for different land uses. Because the results from industrial, commercial, and residential land uses were not significantly different from one another, these data were combined under one “urban” land use category. Runoff from open space contained significantly lower mercury concentrations; therefore, open space data were handled separately. Agricultural drainages were not sampled. Agricultural land was assumed to be like open space in terms of mercury loads. Therefore, for purposes of estimating mercury loads, agricultural land was treated as open space. The agricultural and open space land uses were combined under a “non-urban” land use category. The urban runoff management agencies estimated mercury loads to be about 83 kg/yr for urban areas and about 24 kg/yr for non-urban areas draining to the bay (Kinnetic Laboratories 2002). However, for purposes of this report, these loads have been adjusted for the reasons explained below (SFBRWQCB 2003b).

- This report uses mean (average) sediment mercury concentrations to estimate loads, whereas the urban runoff management programs used medians. When calculating total loads from a number of samples, the mean concentration is more useful than the median (USGS 2002). Averaging the concentration data is equivalent to creating a single composite sample from all the individual samples and using its concentration to estimate loads. In this case, the median mercury concentration was relatively insensitive to data at the low and high ends of the data range, lowering the significance of the mercury concentrations at several locations where measured concentrations were about 10 times higher than the median.

- This report estimates total sediment loads—i.e., suspended loads plus bed loads (some sediment is transported along the bottom without being suspended). In contrast, the urban runoff management agencies estimated suspended sediment loads. The total sediment load is likely to be about 10% greater than the suspended sediment load due to bed load transport (USGS 1980; SFEI 2002c). The U.S. Geological Survey estimated the total sediment load for the local San Francisco Bay tributaries (excluding the Central Valley watershed) to be about 810 M kg/yr on the basis of data representing 1909 to 1966 conditions (USGS 1980). Water resources have not been substantially modified since that estimate was made (U.S. ACE 1992). The U.S. Geological Survey total sediment estimate is about four times greater than the urban runoff management agency suspended sediment estimate, which was based on available rainfall data and approximate runoff fractions, typical suspended sediment concentrations, and estimated area covered by each land use. However, the method the urban runoff management agencies used to estimate suspended sediment loads may understate loads by a factor of two to three (SFEI 2002c). The U.S. Geological Survey total sediment estimate is within the range of several others, which range from 600 to 1,400 M kg/yr (U.S. ACE et al. 1998; Krone 1979). Assuming that about 50% of the total sediment load is discharged from urban areas and about 50% is discharged from non-urban areas (the same ratio the urban runoff management agencies estimated), the total sediment load is about 410 M kg/yr for urban areas and about 400 M kg/yr for non-urban areas.

- This report uses sediment mercury concentration data not normalized to percent fines (primarily silt and clay particles less than 62.5 microns). Because the finer particles typically contain more mercury, normalization is common. Normalization eliminates differences attributable only to variations in the particle size distribution of the different samples. However, normalization could overstate mercury concentrations in urban runoff management runoff if the particle size distribution of the sampled sediment is more like that of total sediment than suspended sediment. The urban runoff management agencies reported mean non-normalized mercury concentrations of 0.38 ppm for urban areas and 0.06 ppm for non-urban areas (SCVURPPP 2003; EOA 2003).

Using Equation 1 to multiply the total sediment load estimates derived from the U.S. Geological Survey's study (410 M kg/yr for urban areas and 400 M kg/yr for non-urban areas) by the mean non-normalized sediment mercury concentrations (0.38 ppm for urban areas and 0.06 ppm for non-urban areas) results in mercury loads of about 160 kg/yr for urban areas and about 25 kg/yr for non-urban areas. These represent about 13% and 2% of the bay's total mercury load.

Guadalupe River Watershed (Mining Legacy)

Operations at the New Almaden mercury mines within the Guadalupe River watershed began in 1846. The mines were the most productive in North America, producing over 40,000 tons of mercury (Bulmore 1953). However, mining left a mercury legacy in piles of waste rock, surface soils, and stream sediment (SFBRWQCB 1998b). This waste contributes substantially to mercury enrichment of Guadalupe River sediment (Thomas et al. 2002). The Guadalupe River also carries mercury in storm water from urban and non-urban areas (discussed above). As shown by Equation 2, to estimate the mercury load for the mining legacy, the load for Guadalupe River storm water is subtracted from the load for the entire Guadalupe River watershed, as estimated below.

Equation 2:

$$\text{Mining Legacy Load} = \text{Entire Watershed Load} - \text{Storm Water Load}$$

Entire Watershed Load

The Guadalupe River watershed's suspended sediment load has been estimated using available rainfall data and approximate runoff fractions, typical suspended sediment concentrations, and relative land use areas. Using this method, the load is 6 to 7 M kg/yr (Kinnetic Laboratories 2002; URS and Tetra Tech 2000). However, this method is believed to underestimate sediment loads by a factor of 2 to 3 (SFEI 2002c). The U.S. Geological Survey has estimated the total Guadalupe River watershed sediment load (suspended plus bed loads) to be about 44 M kg/yr on the basis of field measurements (USGS 1980). This may overstate the sediment load discharged into the bay because substantial amounts of sediment settle in the lower portion of the Guadalupe River, which is regularly dredged. However, because tides also carry bay sediment into the lower reaches of the Guadalupe River (SCVWD 2000), available information is insufficient to determine the relative proportion of watershed sediment dredged from the river.

Near downtown San Jose, at a U.S. Geological Survey sample station, Guadalupe River bed sediment mercury concentrations in 16 samples collected between 1980 and 1989 ranged from 0.03 to 10 ppm. The average concentration was 2.4 ppm (SCVNSCP 1992). These data represent the Guadalupe River watershed better than data for sediment collected at the mouth of the Guadalupe River (Alviso Slough). Alviso Slough sediment contains about 1 ppm mercury (SFEI 2002b), but Alviso Slough is subject to tidal mixing, which tends to dilute the mercury concentration in Guadalupe River sediment (SFBRWQCB 2003d). Also, as indicated above, the Santa Clara Valley Water District dredges upstream portions of the Guadalupe River, which distorts the apparent watershed sediment mercury concentrations when measured downstream.

Using Equation 1, and assuming the sediment load is 44 M kg/yr and the average mercury concentration is 2.4 ppm, the total mercury load associated with the Guadalupe River watershed is about 106 kg/yr.

Storm Water Load

Storm water mercury loads are estimated above for all tributaries flowing directly to San Francisco Bay. To avoid double counting the storm water loads when estimating the Guadalupe River watershed mining legacy load, the storm water loads must be subtracted from the total watershed load. In the Guadalupe River watershed, the ratio of urban storm water sediment to non-urban storm water sediment can be estimated using rainfall data, estimated runoff fractions, typical suspended sediment concentrations for various land uses, and approximate land use areas. Taking into account such factors, about 81% of the total Guadalupe River sediment load is from urban areas and about 19% is from non-urban areas (Kinnetic Laboratories 2002). Since the total sediment load is about 44 M kg/yr (estimated above), the urban sediment load is about 36 M kg/yr, and the non-urban sediment load is about 8.5 M kg/yr. This approach assumes that all sediment discharged from the Guadalupe River would be discharged with or without the mining legacy. This assumption may overstate the Guadalupe River watershed storm water sediment load. Because this load is small compared to the overall storm water sediment load entering the bay, however, the effect of any overstatement is inconsequential.

As discussed above, the estimated average mercury concentrations in storm water sediment is about 0.38 ppm in urban areas and about 0.06 ppm in non-urban areas (Kinnetic Laboratories 2002; SCVURPPP 2003; EOA 2003). Using Equation 1, the urban storm water contribution to the Guadalupe River watershed load is about 14 kg/yr. The non-urban contribution is about 0.5 kg/yr. Together, these loads, which cannot be attributed to the watershed mining legacy, amount to about 14 kg/yr.

Mining Legacy Load

Using Equation 2 and subtracting the storm water loads (14 kg/yr) from the entire Guadalupe River watershed load (106 kg/yr) yields a load representing the watershed's mining legacy—about 92 kg/yr. This represents about 7% of the bay's mercury inputs.

Atmospheric Deposition and Evaporation

Atmospheric Deposition

Mercury in the atmosphere enters San Francisco Bay during dry weather (dry deposition) and rainy weather (wet deposition). To determine the mercury load associated with dry and wet deposition, the Regional Monitoring Program for Trace Substances (RMP) collected ambient air and precipitation samples at three Bay Area sites. The study estimated the average dry deposition rate to be 19 micrograms of mercury per square meter per year ($\mu g/m^2/yr$). The study estimated the average wet deposition rate to be

4.2 μg/m^2/yr. The report concluded that atmospheric deposition of mercury on the bay surface is about 27 kg/yr, "with an error of two to five fold" (SFEI 2001b). This is about 2% of the bay's mercury sources.

This load estimate does not include mercury deposited on the bay's watershed and carried to the bay by runoff. The load associated with such indirect deposition is included in the storm water and Central Valley watershed load estimates. The RMP study estimated indirect deposition on the local watershed (not including the Central Valley) to be about 55 kg/yr (SFEI 2001b). Therefore, of the roughly 180 kg/yr of mercury from storm water (urban and non-urban runoff), as much as 55 kg/yr could result from atmospheric deposition.

Evaporation

The loss of mercury from the bay surface, referred to here as "evaporation," can be estimated on the basis of measured dissolved elemental mercury concentrations, atmospheric mercury concentrations, and estimated wind speeds (Conaway et al. 2003). Bay Area winds vary greatly depending on the season. In summer, they are typically much stronger than in winter and temperatures are higher; therefore, more mercury evaporates during summer. Summer evaporation rates range from 100 to 400 μg/m^2/yr. Winter evaporation rates range from 20 to 100 μg/m^2/yr. Assuming a surface area for San Francisco Bay of 1.24 x 10^9 square meters (SWRCB 2003), summer conditions result in mercury losses of 120 to 500 kg/yr. Winter conditions result in mercury losses of 27 to 120 kg/yr. Although meteorological conditions vary substantially, for purposes of this report, the midpoints of these ranges (the value most likely to be representative of overall conditions)—310 kg/yr for summer and 75 kg/yr for winter—are used to estimate summer and winter evaporation rates. Assuming that summer conditions prevail for half the year and winter conditions prevail for the other half, the typical mercury load lost from the bay's surface each year is roughly the average of the summer and winter evaporation rates, or about 190 kg/yr. This is about 11% of the bay's mercury losses. When considered with estimated direct atmospheric deposition on the bay (estimated above to be about 27 kg/yr), there is a net loss to the atmosphere of about 160 kg/yr.

Wastewater

The federal Clean Water Act requires NPDES permits for wastewater discharges. In the Bay Area, the Regional Board issues and administers these permits, which impose requirements on wastewater quality and monitoring. Wastewater treatment plants collect and analyze mercury in their effluent using "ultra-clean" methods capable of detecting extremely low mercury concentrations. The NPDES program covers municipal wastewater treatment plants (see Table 4.3) and industrial dischargers (see Table 4.4).

In the Bay Area, municipal wastewater treatment plants provide secondary treatment, which includes settling, filtration, and biological treatment. Some plants also provide advanced treatment, which removes additional solids. Removing additional solids removes additional pollutants, like mercury, that adhere to particles. Municipal

TABLE 4.3: Municipal Wastewater Dischargers to San Francisco Bay and its Tributaries*

Permit Holder	Permit Number
American Canyon	CA0038768
Angel Island State Park	CA0037401
Benicia	CA0038091
Burlingame	CA0037788
Calistoga	CA0037966
Central Contra Costa Sanitary District	CA0037648
Central Marin Sanitation Agency	CA0038628
Delta Diablo Sanitation District	CA0038547
Dublin San Ramon Services District	CA0037613
East Bay Dischargers Authority	CA0037869
East Bay Municipal Utilities District	CA0037702
Fairfield-Suisun Sewer District	CA0038024
Las Gallinas Valley Sanitary District	CA0037851
Livermore, City of	CA0038008
Marin County Sanitary District	CA0037753
Millbrae	CA0037532
Mountain View Sanitary District	CA0037770
Napa Sanitation District	CA0037575
Novato Sanitary District	CA0037958
Palo Alto	CA0037834
Petaluma	CA0037810
Pinole-Hercules	CA0037796
Port Costa Wastewater Treatment Plant	CA0037885
Rodeo Sanitary District	CA0037826
Saint Helena	CA0038016
San Francisco International Airport	CA0038318
San Francisco, Southeast	CA0037664
San Francisco, Wet Weather (Bayside)	CA0038610
San Jose & Santa Clara	CA0037842
San Mateo (city)	CA0037541
Sausalito-Marin Sanitary District	CA0038067
Seafirth Estates	CA0038893
Sewerage Agency of Southern Marin	CA0037711
Sonoma Valley	CA0037800
South Bayside System Authority	CA0038369
South San Francisco & San Bruno	CA0038130
Sunnyvale	CA0037621
Treasure Island	CA0110116
Vallejo Sanitation & Flood Control District	CA0037699
West County/Richmond	CA0038539
Yountville	CA0038121

* Does not include wastewater dischargers outside the jurisdiction of the San Francisco Bay Regional Water Quality Control Board.

TABLE 4.4: Industrial Wastewater Dischargers to San Francisco Bay and its Tributaries*

Permit Holder	Permit Number
Astoria Metals Corporation	CA0028282
Bay Ship and Yacht Company	CA0030121
C&H Sugar Co.	CA0005240
Cargill Salt Division, Newark Facility	CA0028703
Cargill Salt, Redwood City	CA0028690
Chevron	CA0005134
City of San Jose, Story Road Landfill	CA0029939
ConocoPhillips	CA0005053
Crockett Cogeneration	CA0029904
Dow Chemical	CA0004910
General Chemical	CA0004979
GWF Power Systems 3rd Street	CA0029106
GWF Power Systems Nichols Road	CA0029122
Hanson Aggregates, Amador Street	CA0030139
Hanson Aggregates, Olin Jones Dredge Spoils Disposal	CA0028321
Hanson Aggregates, Tidewater Ave. Oakland	CAA038351
Morton Salt Company, Newark	CA0005185
Pacific Gas and Electric and East Shell Pond	CA0030082
Pacific Gas and Electric, Hunters Point Power Plant	CA0005649
Rhodia	CA0006165
San Francisco Drydock, Inc.	CA0005321
San Francisco International Airport	CA0028070
Shell	CA0005789
Southern Energy, Pittsburg Power Plant	CA0004880
Southern Energy, Potrero Power Plant	CA0005657
Ultramar (Golden Eagle)	CA0004961
United States Navy supply center at Point Molate	CA0030074
US Department of Defense, Point Ozol Facility (under general permit)	CAG912003
USS-Posco	CA0005002
Valero	CA0005550

* Does not include wastewater dischargers outside the jurisdiction of the San Francisco Bay Regional Water Quality Control Board.

wastewater treatment plants remove over 90% of the mercury in their influent (AMSA 2000). While the removed mercury is not directly discharged to water, some is returned to the environment through landfills, incinerators, or soil amendments. The primary sources of mercury in municipal wastewater are human waste and medical and dental facilities (Palo Alto RWQCP 1999).

Industrial dischargers include petroleum refineries, chemical plants, and other large industrial facilities. Their mercury loads depend on the types of activities in which these dischargers engage. Because wastewater dischargers regularly monitor and report their discharges, their combined loads can be estimated more precisely than any of the other loads estimated in this report. Available data are sufficient to allow statistical analyses that quantitatively characterize variations from year to year. The combined mercury load for all municipal wastewater discharges to San Francisco Bay and its tributaries is about 17 kg/yr. The combined load of the industrial dischargers is about 2.1 kg/yr (LWA 2002; SFBRWQCB 2003i).

Together, these municipal and industrial wastewater discharges account for a load of about 19 kg/yr, or about 2% of the bay's total mercury load. These loads do not reflect wastewater discharged in the Central Valley, which is included in the estimate for the Central Valley watershed, above.

Sediment Dredging and Disposal

From time to time, sediment is dredged from San Francisco Bay channels to accommodate navigation. Some dredging is routine channel maintenance, and some is construction-related. Beginning in the 1970s, most dredged material was disposed of near Alcatraz Island. Other in-bay disposal sites are in San Pablo Bay, Carquinez Strait, and Suisun Bay. Sediment disposed of near Alcatraz Island was expected to disperse, but a sizeable mound grew, posing potential navigation problems. To improve dredged material management and disposal, the San Francisco Bay Regional Water Quality Control Board joined the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, San Francisco Bay Conservation and Development Commission, and State Water Resources Control Board in developing the *Long Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region* (LTMS). The LTMS seeks to reduce the volume of dredged material disposed of in San Francisco Bay by shifting disposal to ocean and upland disposal sites (U.S. ACE et al. 2001).

Available data include the volumes of material dredged for channel maintenance disposed of at in-bay disposal sites and at sites outside the bay. As shown in Table 4.5, between 1991 and 1999, the amount of dredged material disposed of each year at in-bay disposal sites averaged 2,300,000 cubic yards (U.S. ACE et al. 2001). In 1999, 2000, and 2001, the average out-of-bay dredged material disposal volume was 700,000 cubic yards (U.S. ACE 2002a). Volumes vary substantially from year to year because channels do not need to be dredged every year. Dredging occurs when needed and when funds are

TABLE 4.5: Dredged Material Volumes, Sediment Masses, and Mercury Loads

	Average Volume (yd^3/yr)	Average Sediment Mass (M kg/yr)*	Average Estimated Mercury Load (kg/yr)
Material dredged (loss)	3,000,000	1,700	640
In-bay disposal (source)	2,300,000	1,300	490
Out-of-bay disposal (net loss)	700,000	400	150

* Assumes dredged material is 50% water and 50% sediment by weight (U.S. ACE 2002b) and there are about 570 kilograms of dry sediment per cubic yard of wet dredged material (Weast 1981; Elert 2002).

available, or when special projects are needed. The total amount of material dredged from the bay is the sum of the in-bay and out-of-bay disposal volumes, or about 3,000,000 cubic yards per year.

Dredged material consists of sediment and water. Assuming that dredged material is 50% water and 50% sediment by weight (U.S. ACE 2002b), there are about 570 kilograms of dry sediment per cubic yard of wet dredged material (Weast 1981; Elert 2002). Therefore, the amount of sediment dredged from the bay (a loss) is about 1,700 M kg/yr. The amount of sediment returned to the bay for disposal (a source) is about 1,300 M kg/yr. The net sediment loss is about 400 M kg/yr.

In 2000 and 2001, mercury concentrations were measured in samples representing about 73% of the dredged material disposed of in the bay. On a volume-weighted basis, the average mercury concentration was about 0.37 ppm (SFBRWQCB 2002d). Inserting this concentration into Equation 1, the mercury load from in-bay dredged material disposal is about 490 kg/yr. Assuming that the concentration of mercury in sediment disposed of at out-of-bay sites is the same as that disposed of in-bay, the mercury loss from dredging is about 640 kg/yr. The net loss from the combined processes of dredging and disposal is about 150 kg/yr. This represents about 8% of the mercury leaving San Francisco Bay each year.

Transport Through Golden Gate to Ocean

The net sediment discharge through the Golden Gate to the ocean is difficult to estimate because sediment moves back and forth through the Golden Gate with tides and weather conditions. Several estimates exist, ranging from 1,900 to 4,600 M kg/yr (U.S. ACE et al. 1998; U.S. ACE 1992; Krone 1979). With the steady state one-box model described in Section 3, Mass Budget Approach, sediment loads leaving through the Golden Gate can be estimated from the sediment loads estimated for the other sources and losses discussed above. Assuming the sediment load entering the bay equals the sediment load leaving the bay, the Golden Gate load equals the sum of the sediment loads entering the bay minus the other sediment losses. The major sediment source loads are as follows:

- Bed Erosion—1,100 M kg/yr
- Central Valley Watershed—1,600 M kg/yr
- Urban Storm Water—410 M kg/yr
- Non-Urban Storm Water—400 M kg/yr

The total of all sediment sources is about 3,600 M kg/yr. (Because sediment associated with the Guadalupe River watershed is a subset of the total sediment load estimated for storm water, this sediment load is not counted twice in the calculation.) Dredging and disposal involves a net sediment loss of about 400 M kg/yr. Subtracting this loss results in the net sediment transported to the ocean through the Golden Gate—3,200 M kg/yr. This estimate is within the range of other available estimates (U.S. ACE et al. 1998; U.S. ACE 1992; Krone 1979).

The mercury in exported sediment comes from all over San Francisco Bay. On the basis of data from the Regional Monitoring Program for Trace Substances, the overall concentration of mercury in bay suspended sediment averages 0.44 ppm (SFBRWQCB 2002c). Using Equation 1, the mercury load lost through the Golden Gate is about 1,400 kg/yr—about 81% of the mercury exiting the bay.

Other Potential Sources

In addition to the mercury sources and losses quantified above, there may be other less understood sources that are yet to be discovered. These may include mining sources in local tributaries other than the Guadalupe River watershed (SFBRWQCB 1998b) and contaminated sites within and in the vicinity of the bay (SWRCB 1999a). The potential mercury loads that could be associated with these potential sources are unknown.

Table 4.6 lists mines that could be potential sources of mercury to San Francisco Bay (SFBRWQCB 1998b). Implementing the Regional Board's mines program as described in the Basin Plan involves inspecting these mine sites, identifying and contacting the property owners, notifying local agencies, implementing site management plans, assessing loads and risks, identifying previous owners, issuing permits or orders, initiating remediation, and following up with monitoring (SFBRWQCB 1995). Existing information is insufficient to estimate the potential loads from these mines. However, the margin of safety discussed in Section 7, Allocations, is intended to account for this uncertainty. Moreover, Section 8, Implementation Plan, includes measures to investigate and address potential mercury discharges from Bay Area mines.

TABLE 4.6: Bay Area Mercury Mines

Mine	County	Drainage
Bella Oaks	Napa	Napa River
Borges	Napa	American Canyon Creek
Challenge	San Mateo	Arroyo Ojo de Agua
Corda	Marin	San Antonio Creek
Hastings	Solano	Sulphur Springs Creek
La Joya	Napa	Dry Creek / Napa River
New Almaden / Guadalupe *	Santa Clara	Guadalupe River
Saint Johns	Solano	Rindler Creek
Silver Creek	Santa Clara	Silver Creek

* The New Almaden Mining District encompasses a number of mines that drain into the Guadalupe River watershed. Associated mercury loads are accounted for in the Guadalupe River Watershed load estimate and, therefore, are not "other potential sources."
Source: SFBRWQCB 1998b

Sediment at some sites along the margins of San Francisco Bay contains elevated mercury concentrations. Some sites have been identified through the Regional Monitoring Program for Trace Substances, the Bay Protection and Toxic Cleanup Program, the State Mussel Watch Program, and individual site investigations. Other sites may remain to be discovered. Table 4.7 provides some examples of known bay margin contaminated sites. At each of these sites, at least one sediment sample contained a mercury concentration above the non-regulatory screening value 0.71 ppm. This value is the Effects Range Median (ERM) concentration, which is the mercury concentration at which adverse biological effects have been reported in 50% of National Oceanic and Atmospheric Administration data. Sites that exceed this threshold represent some of the most contaminated bay margin sites. Table 4.7 estimates of the mass of mercury at each site (URS 2002). The extent to which this mercury affects beneficial uses or influences mercury concentrations in the bay is unknown. However, the margin of safety discussed in Section 7, Allocations, is intended to account for this uncertainty. Moreover, Section 8, Implementation Plan, includes measures to investigate and address potential mercury effects from bay margin contaminated sites.

TABLE 4.7: Examples of Bay Margin Sites with Elevated Mercury Concentrations

Site	Average Mercury Concentration (ppm)	Estimated Mercury Mass (kg)
Treasure Island Air Station – Area B	0.62	4.8
Treasure Island Air Station – Area E	0.51	1.0
Hamilton Army Air Field	0.6	3.0
U.C. Berkeley Richmond Field Station	16	130
Zeneca – Stege Marsh	5.2	22
Alameda Seaplane Lagoon	1.0	36
Castro Cove	2.3	4.4
Point Potrero	4.7	3.1
Pacific Dry Dock	1.3	*NA*
San Leandro Bay	0.77	3.0
San Francisco International Airport	1.9	*NA*

Source: URS 2002
NA = not available

Key Points

- About 1,220 kg of mercury enters San Francisco Bay each year.
- The sources of mercury in San Francisco Bay include bed erosion (about 460 kg/yr), the Central Valley watershed (about 440 kg/yr), urban storm water runoff (about 160 kg/yr), the Guadalupe River watershed (about 92 kg/yr), direct atmospheric deposition (about 27 kg/yr), non-urban storm water runoff (about 25 kg/yr), and wastewater discharges (about 19 kg/yr).
- San Francisco Bay loses mercury as sediment is transported to the ocean through the Golden Gate (about 1,400 kg/yr), mercury evaporates from the bay surface (about 190 kg/yr), and dredged material is removed and disposed of (about 150 kg/yr, net).

5. Numeric Targets

Numeric targets are measurable conditions that demonstrate attainment of water quality standards. A numeric target can be a numeric water quality objective, a numeric interpretation of a narrative objective, or a numeric measure of some other parameter necessary to meet water quality standards. For a complex problem, such as mercury bioaccumulation in a large estuary, multiple targets may be needed. This report proposes targets for mercury concentrations in San Francisco Bay fish tissue, bird eggs, and sediment. In Section 7, Allocations, the sediment target serves as a basis for allocating loads for several mercury sources. In Section 8, Implementation Plan, the fish tissue and bird egg targets serve to guide management actions needed to minimize mercury methylation and bioaccumulation. These targets are intended to protect the beneficial uses of San Francisco Bay.

Fish Tissue Target

The method used to develop a target for San Francisco Bay fish tissue is derived from the method the U.S. Environmental Protection Agency (U.S. EPA) used to develop its national criterion for mercury in fish tissue (U.S. EPA 2001). To protect human health, U.S. EPA developed a criterion of 0.3 milligrams mercury per kilogram fish tissue (i.e., parts per million, ppm) using Equation 3:

Equation 3:

$$\text{Criterion} = \frac{\text{Body Weight x (Reference Dose - Relative Source Contribution)}}{\text{Fish Intake}}$$

U.S. EPA assumed an adult body weight of 70 kilograms. The reference dose in the equation is 0.0001 milligrams mercury per kilogram body weight per day (mg/kg-day). It represents a lifetime daily exposure level at which no adverse effects would be expected. It is derived from mercury levels that studies have shown cause toxic effects in children exposed to mercury prior to birth. Adverse developmental effects are the most sensitive indicator of mercury effects. U.S. EPA's approach for developing its fish tissue criterion includes several additional conservative assumptions, including incorporating a factor of 10 in the reference dose to account for uncertainties related to mercury's health effects and its metabolism within the body. The relative source contribution (0.000027 mg/kg-day) accounts for other sources of mercury exposure (U.S. EPA 2001).

U.S. EPA recommends that states adopt their own water quality criteria using local consumption data (U.S. EPA 2001). U.S. EPA used 0.0175 kilograms per day as a default fish intake rate. This rate represents the 90th percentile of the U.S. population, including those who do and do not consume fish. However, Bay Area sport fishers (anglers) and subsistence fishers have different fish consumption patterns than the general U.S. population.

To protect the bay's beneficial use of sport fishing, mercury concentrations in bay fish should be low enough so people who choose to eat bay fish can do so on a regular basis. Roughly 170,000 sport and subsistence fishers currently choose to consume bay fish (U.S. EPA 1997d). According to a survey of these fishers, 95% eat less than 0.032 kilograms of fish per day (CDHS and SFEI 2000). Substituting this fish intake rate into the equation above results in a fish tissue criterion of 0.2 ppm mercury. Therefore, 0.2 ppm mercury in fish tissue is proposed as a target to protect human health.

The estimated 170,000 Bay Area sport and subsistence fishers (U.S. EPA 1997d) represent about 3% of the roughly 6,000,000 people who live in the Bay Area (CDFFP 1999; CDF 2000). Because the proposed target protects the 95th percentile of these fishers, it protects well over 99% of the Bay Area's existing population.

According to surveys of contaminant levels in fish conducted by the Regional Monitoring Program for Trace Substances (RMP) in 1994, 1997, and 2000, many San Francisco Bay fish that humans consume contain greater than 0.2 ppm mercury, as shown in Figure 5.1. An individual fish consumer's mercury exposure is a function of the type of fish consumed, the amount consumed, and the frequency of consumption. Because the target is derived from a level of daily exposure assumed to occur over an entire lifetime, some fish above the target could be consumed if others were well below it. Therefore, the fish

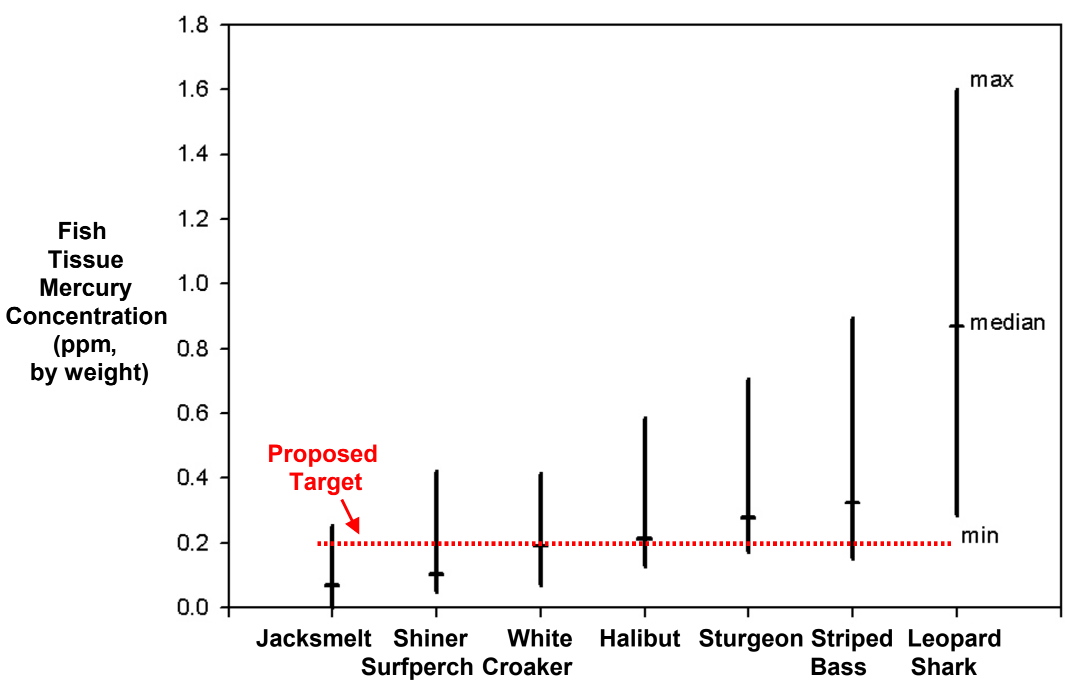

FIGURE 5.1: Mercury Concentrations in San Francisco Bay Fish
San Francisco Bay fish tissue mercury concentrations (ppm, wet weight) were measured in 1994, 1997, and 2000 (SFEI 2003a).

tissue target applies to the average mercury concentration in a collection of fish representing typical consumption patterns.

Striped bass is among the fish species with the highest observed mercury tissue concentrations. Surveys indicate that about 78% of sport and subsistence fishers report consuming striped bass, although the relative proportion of striped bass within their diet is unknown (CDHS and SFEI 2000). This contrasts with 20% reporting leopard shark consumption. Because consumers favor striped bass and striped bass contain relatively high mercury concentrations, achieving 0.2 ppm mercury in striped bass would likely achieve the proposed target in bay fish that represent typical consumption patterns. To lower the mercury concentration in striped bass to 0.2 ppm, concentrations would need to be reduced by about 40%.

Wildlife Target

Whereas fish consumption accounts for only a portion of most human diets, some wildlife depend entirely on bay fish or other aquatic organisms for their food. Numerous studies document mercury accumulation within the aquatic food web and its toxic effects on birds (Wiener et al., in press). In the Bay Area, birds feeding on fish and other aquatic organisms are among the most sensitive wildlife mercury receptors (CDFG 2002). A wildlife target that protects birds is also expected to protect other wildlife reliant on the bay for food.

The relationship between mercury concentrations in aquatic organisms and the dietary mercury exposure of Bay Area birds varies (CDFG 2002). Diets vary by bird species and location. Prey mercury concentrations vary by prey size and position in the food web. For example, some bird species eat more fish than others, some fish contain more mercury than others, and some birds are more sensitive to mercury than others. The links between mercury concentrations in San Francisco Bay water, aquatic prey, and wildlife are not understood in detail (see Section 6, Linkage Analysis). Therefore, to protect wildlife, this report proposes a target for mercury in bird eggs instead of water column or fish tissue targets. In addition to protecting sensitive wildlife receptors, the proposed bird egg target is closely related to the beneficial uses of the bay that mercury threatens—wildlife habitat and preservation of rare and endangered species.

For birds, consumption of mercury in prey is the main route for mercury exposure. The life stage most vulnerable to mercury toxicity is the developing embryo (CDFG 2002). Dietary concentrations of mercury that significantly impair bird reproduction are about one-fifth of those that produce overt toxicity in adults (Wiener et al., in press). Egg mercury concentrations reflect the pre-laying diet of the parent and are predictive of reproduction risks. Reproductive harm ranges from behavioral changes in young birds to egg hatch failure (Davis et al., in press).

Egg concentrations above 0.5 micrograms of mercury per gram of egg (parts per million, ppm, wet weight) have been associated with toxic effects (CDFG 2002; U.S. EPA 1997c). In a study of common terns, egg mercury concentration between 1.0 and

3.6 ppm adversely affected nesting success (Fimreite 1974). In a ring-necked pheasant feeding study, egg mercury concentrations between 0.5 and 1.5 ppm significantly reduced hatching success (Fimreite 1971). In a study of mallard ducks fed a diet containing 0.5 ppm mercury, egg mercury concentrations were about 0.8 ppm and sublethal effects were observed (Heinz 1979). The lowest observed adverse effect mercury concentration in a bird's diet was about 0.064 micrograms per gram body weight per day, which corresponded to average egg mercury concentrations of about 0.86 ppm (Davis et al., in press). These studies support the conclusion that bird egg concentrations above 0.5 ppm could be associated with toxic effects, but they do not fully explore the potential for different species to be more or less sensitive to mercury.

Because available information suggests that bird egg mercury concentrations below 0.5 ppm do not cause adverse effects, a bird egg target of 0.5 ppm mercury (wet weight) is proposed. However, because mercury toxicity may vary by species, new information could become available in the future that could show that this target is under-protective. To refine the proposed target, species-specific mercury toxicity thresholds are needed. The goal of refining the target would be "no detrimental increase in mercury concentrations in San Francisco Bay bird eggs," which is consistent with the Basin Plan's narrative objective for bioaccumulation. Such a refinement would protect all wildlife and birds, including rare and endangered species that nest and feed in the vicinity of San Francisco Bay.

Table 5.1 presents results from a San Francisco Bay bird study that involved collecting and analyzing 328 eggs from 10 different species, including three federally protected species: California clapper rail, California least tern, and Western snowy plover. Eggs were collected across the entire bay region. Average bird egg mercury concentrations for Caspian tern, Forster's tern, and California clapper rail exceeded 0.5 ppm. Average mercury concentrations were less in other species' eggs (CDFG 2002). For average bird egg mercury concentrations to reach 0.5 ppm, existing concentrations will need to be reduced by 50%.

Sediment Target

This report proposes a target for sediment mercury concentration (particle-bound mercury mass divided by sediment mass). Sediment mercury concentrations are closely linked to mercury sources (see Section 6, Linkage Analysis). A sediment mercury target is preferable to a water column mercury target because sediment mercury concentrations relate better to the amount of mercury in the bay and are less subject to short-term fluctuations. The amount of suspended sediment in the water column fluctuates greatly throughout the bay with seasonal and tidal changes (SFEI 1997). Likewise, water column mercury concentrations fluctuate in response to suspended sediment changes. The proposed sediment mercury target is not subject to these confounding factors. The proposed sediment mercury target is useful in allocating mercury loads, as done in Section 7, Allocations.

TABLE 5.1: 2000 and 2001 Mercury Concentrations in San Francisco Bay Bird Eggs

Bird Species	Number of Eggs Examined	Approximate Average Mercury Concentration in Eggs (ppm, wet weight)
American avocet	16	0.19
Black-crowned night heron	28	0.13
Black-necked stilt	13	0.31
California clapper rail*	6	0.81
California least tern*	*NA*	0.30
Caspian tern	15	0.93
Forster's tern	21	0.83
Snowy egret	18	0.16
Western snowy plover*	3	0.45

Source: CDFG 2002
NA = not available
*Only eggs that failed to hatch were collected.

RMP data collected from 1993 through 2000 can be used to determine the current median suspended sediment mercury concentration. As shown in Equation 4, the dissolved mercury concentration for each RMP sample is subtracted from the total mercury concentration. The difference (the particle-bound mercury concentration) is divided by the total suspended sediment concentration to obtain the suspended sediment mercury concentration.

Equation 4:

$$[\text{mercury}]_{\text{sediment}} = \frac{[\text{mercury}]_{\text{total}} - [\text{mercury}]_{\text{dissolved}}}{[\text{suspended sediment}]}$$

where: $[\text{mercury}]_{\text{sediment}}$ = mercury concentration in suspended sediment (dry)
$[\text{mercury}]_{\text{total}}$ = total mercury concentration in water
$[\text{mercury}]_{\text{dissolved}}$ = dissolved mercury concentration in water
[suspended sediment] = suspended sediment concentration

The current median suspended sediment mercury concentration is about 0.3 milligrams mercury per kilogram dry sediment (parts per million, ppm) (SFBRWQCB 2002c). The central tendency of the RMP data is best represented by the median because the data appear to be log-normally distributed.

To meet the proposed fish tissue and interim bird egg targets, a 40 to 50% reduction is needed in the amount of mercury in San Francisco Bay sediment. (Section 6, Linkage Analysis, discusses the relationship between mercury in sediment and mercury in fish tissue and bird eggs.) If each individual RMP sample's sediment mercury concentration were reduced by 50%, the median suspended sediment mercury concentration would decrease to about 0.2 ppm (assuming the fraction of dissolved mercury in each sample were to remain the same). Reducing each individual sample's sediment mercury concentration by 50% would effectively reduce the total amount of mercury in the system by 50%. Therefore, a median sediment mercury concentration of 0.2 ppm is proposed as the sediment mercury target.

This proposed target is consistent with Basin Plan and California Toxics Rule water quality objectives. Figure 2.1 shows that about 21% of RMP samples from 1993 through 2000 exceeded 0.025 micrograms of mercury per liter of water (µg/l). As illustrated in Figure 5.2, if all sediment mercury concentrations were reduced by 50%, the proposed sediment target of 0.2 ppm would be met, and only 46 out of 465 samples (about 10%) would exceed 0.025 µg/l during this eight-year period.

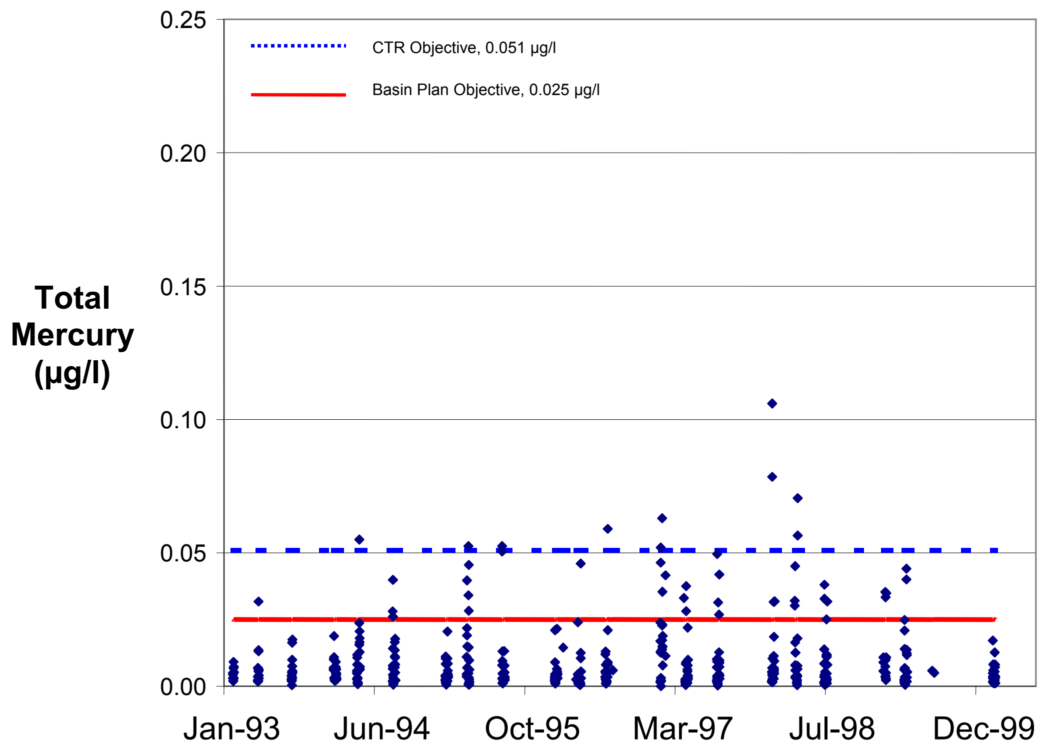

FIGURE 5.2: Predicted Total Mercury Concentrations in Water with 50% Reduction in Sediment Mercury Concentrations
Much of the mercury in San Francisco Bay is bound to suspended sediment. By reducing sediment mercury concentrations by 50%, total mercury concentrations would decrease as illustrated (compare with Figure 2.1). The number of samples shown is 465. Two extreme values from the Guadalupe River are not shown in this figure because they are beyond the scale. The median mercury concentration would be 0.00475 µg/l. The value 0.025 µg/l is exceeded 46 times during this eight-year period.

Reducing the frequency of total mercury concentrations exceeding 0.025 μg/l illustrates the benefit of achieving the proposed sediment target. However, this comparison does not suggest that the target is inconsistent with the 0.025 μg/l Basin Plan objective. The RMP's instantaneous grab samples do not represent the four-day average concentrations associated with the Basin Plan objective. Suspended sediment levels can fluctuate by as much as 100 milligrams per liter or more on a daily basis (Schoellhamer 1996), and total mercury concentrations fluctuate significantly over four-day periods.

As an illustration, the variability in suspended sediment concentrations over a four-day period beginning March 16, 1997, is shown in Figure 5.3 (SFBRWQCB 2002b). The bottom curve is the calculated total mercury concentration in the water column that would have resulted if the suspended sediment had a mercury concentration of 0.2 ppm (the proposed target). The four-day average concentration in this scenario is 0.021 μg/l, well below the Basin Plan objective of 0.025 μg/l and the California Toxics Rule objective of 0.051 μg/l. In this case, 22% of the estimated sediment mercury concentrations during the four-day period exceed 0.025 μg/l. Therefore, with a sediment mercury target of 0.2 ppm, occasional short-term (less than four-day) excursions above 0.025 μg/l total water column mercury may continue to occur, but actual exceedances of the Basin Plan objective would be rare.

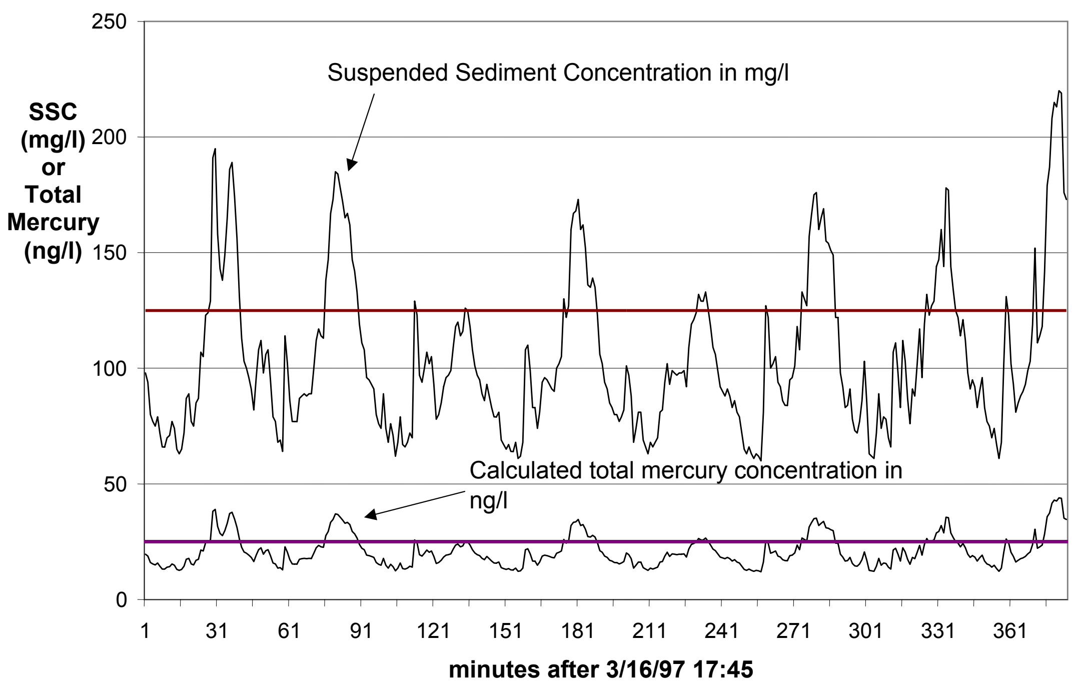

FIGURE 5.3: Suspended Sediment and Estimated Mercury Concentrations for a Four-Day Period

Data (upper plot) represent four days of continuous 15-minute average, mid-depth, suspended sediment concentrations (SSC) at the Dumbarton Bridge as measured by the U.S. Geological Survey. Calculated total mercury concentration (lower plot) is computed from an assumed mercury concentration of 0.2 ppm (the proposed target) on suspended particles.

Antidegradation

The numeric targets must be consistent with antidegradation policies. Section 131.12 of Title 40 of the Code of Federal Regulations contains the federal antidegradation policy. State Water Resources Control Board Resolution 68-16 contains California's antidegradation policy. These antidegradation policies are intended to protect beneficial uses and the water quality necessary to sustain them. When water quality is sufficient to sustain beneficial uses, it cannot be lowered unless doing so is consistent with the maximum benefit to the citizens of California. Even then, water quality must sustain existing beneficial uses.

The proposed numeric targets are designed to implement the narrative water quality objective for bioaccumulation and the Basin Plan and California Toxic Rule numeric water quality objectives for mercury in water. The targets are essentially translations of the narrative and numeric objectives, which have already been established. To be consistent with the antidegradation policies, these targets, taken together, cannot be less stringent than the existing water quality objectives. The proposed combination of the numeric targets is as protective as the objectives. Since mercury concentrations already exceed the bioaccumulation objective, meeting the numeric targets would improve current water quality conditions. Therefore, the proposed targets are consistent with the antidegradation policies and the protection of water quality and beneficial uses.

Key Points

- To protect sport fishing and human health, the concentration of mercury in fish tissue must be reduced by about 40% to 0.2 ppm.
- To protect wildlife and rare and endangered species, the concentration of mercury in bird eggs must be reduced by about 50% to 0.5 ppm.
- To achieve the fish tissue and bird egg targets and to attain water quality standards, the concentration of mercury in sediment must be reduced by about 50%; the median concentration of mercury in sediment should be 0.2 ppm.
- The proposed targets are consistent with antidegradation policies.

6. Linkage Analysis

In Section 5, Numeric Targets, the proposed numeric targets are linked to water quality standards. The proposed targets are intended to ensure attainment of water quality objectives and protection of beneficial uses. This linkage analysis links the proposed targets to the sources of mercury in San Francisco Bay. By linking the targets to the sources, this report demonstrates how actions taken to control mercury sources will achieve the proposed targets and ensure attainment of water quality standards. This analysis also estimates San Francisco Bay's capacity to assimilate mercury while still attaining water quality standards.

Links between Sources and Targets

As discussed in Section 3, Mass Budget Approach, mercury fate and transport within San Francisco Bay is complex. Figure 6.1 simplifies the system to illustrate the primary links between the mercury sources and the proposed sediment, fish tissue, and bird egg targets. The principal steps are as follows:

1. Most mercury in San Francisco Bay binds to sediment.

2. Water movement within the bay transports mercury-laden sediment throughout the bay, depositing some in wetlands, mudflats, and sloughs, where conditions favor methylmercury formation.

3. Small aquatic organisms, such as plankton, take in methylmercury and pass it up through the food web to higher organisms, such as fish.

4. Wildlife and birds at the top of the food web consume mercury in fish and other aquatic organisms (e.g., clams, snails, crabs, and worms).

Mercury Sources and Sediment

The proposed sediment target is closely linked to the sources of mercury in San Francisco Bay because mercury exhibits a high affinity for particles. Most mercury in the aquatic environment is sediment-bound (Morel et al. 1998). The sediment-to-water partition coefficient (K_{db}) for inorganic mercury is typically between 16,000 and 990,000 milliliters per gram (U.S. EPA 1997a). In other words, at equilibrium, a mass of sediment contains roughly 16,000 to 990,000 times more inorganic mercury than an equal mass of water. Therefore, most mercury in San Francisco Bay is sediment-bound.

As explained in Section 4, Source Assessment, tributaries, such as the Sacramento and San Joaquin Rivers, the Guadalupe River, and other local tributaries carrying storm water runoff, are the largest sources of mercury in San Francisco Bay. These tributaries carry substantial sediment loads, and most of the mercury they deliver is bound to sediment by the time it arrives at the bay. In contrast, the relatively small mercury load from

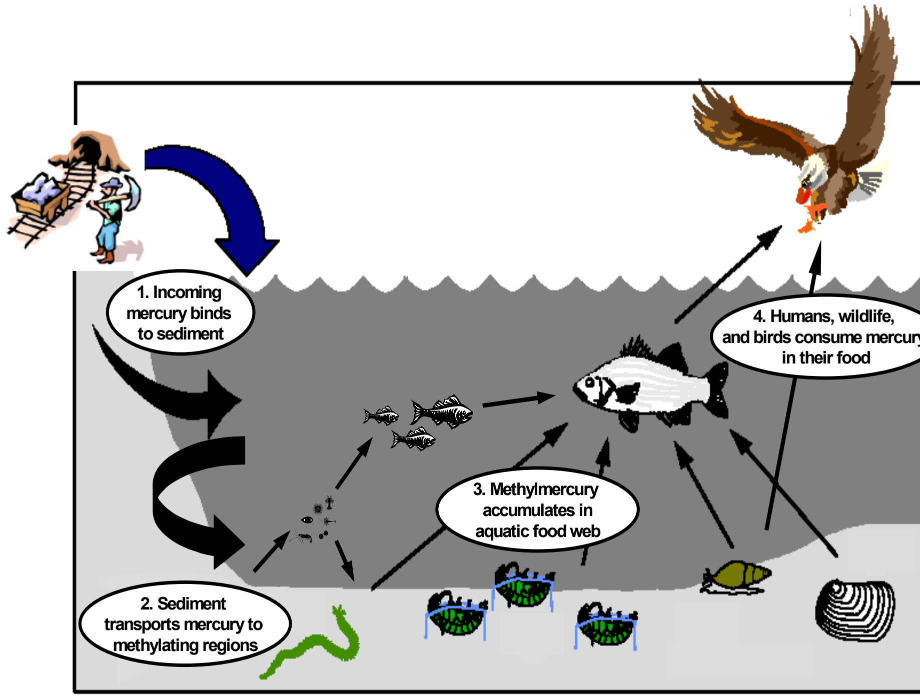

FIGURE 6.1: Simple Conceptual Model
Much of the mercury from the various sources binds to sediment. Some of this mercury is converted to methylmercury, which accumulates in the aquatic food web. Humans, wildlife, and birds are exposed to mercury in the fish and other aquatic organisms they consume.

wastewater is primarily dissolved because treatment processes trap and remove most particles (AMSA 2000). The relatively small atmospheric deposition load is typically inorganic and may be either particle-bound or not (Morel et al. 1998). Although a relatively small amount of mercury enters the bay not bound to sediment, because of mercury's affinity for sediment, most of this mercury likely binds to sediment after it arrives. Because the amount of mercury in bay sediment is closely related to the mercury loads from the various mercury sources, reducing mercury loads will reduce mercury concentrations in sediment.

Methylmercury Production

The bay is a dynamic system, where water and sediment are mixed by tides, wind, and tributary flows (STB et al. 2000). Mercury is transported with sediment. As sediment moves through the bay, a portion may be transported to areas that favor methylmercury production. Mercury methylation is the conversion of inorganic mercury to organic methylmercury. Demethylation is the opposite process. Both methylation and demethylation occur in San Francisco Bay, and the term "methylation" often refers to net methylmercury production (as in this report). The Regional Monitoring Program for Trace Substances has detected methylmercury in the bay (SFEI 2003b).

Different bay regions can vary considerably in their methylation potential. Areas that favor methylmercury production include wetlands, marshes, and brackish areas, such as sloughs. Factors that facilitate methylation include the presence of organic matter, low-oxygen sediment, high microbial activity, and water-level fluctuations (Wiener et al., in press). Methylation rates also depend on pH, temperature, and oxygen levels (DTMC and SRWP 2002). For example, low-oxygen waters can inhibit demethylation, thereby increasing net methylation (DTMC and SRWP 2002; Morel et al. 1998). A study by a Bay Area advanced wastewater treatment plant reported that the ratio of methylmercury to total mercury (fraction methylated) increases when dissolved oxygen decreases below 7 milligrams per liter (FSSD 2002) (the current Basin Plan water quality objective for dissolved oxygen [SFBRWQCB 1995]). Because the factors that affect methylmercury production vary throughout San Francisco Bay, methylation rates also vary.

Sulfate-reducing bacteria are considered to be among the most important methylating agents in aquatic systems (Gilmour et al. 1992). Sulfate-reducing bacteria are most active at the interfaces of water high in oxygen and water low in oxygen, and in sediment and wetlands. In sediment, the microbial methylation of mercury is most rapid in the uppermost 5 centimeters (Wiener et al., in press). Mercury buried below surface sediment is not readily converted to methylmercury because microbial activity is lacking (Rudd et al. 1983).

Methylmercury production at any particular site is strongly influenced by total mercury in local surface sediment (Rudd et al. 1983). Mercury methylation rates in surface sediment directly relate to mercury concentrations in the sediment when sediment concentrations are less than 1 ppm (USGS 2001c). The median concentration of mercury in bay sediment is about 0.3 ppm (SFBRWQCB 2002c). Therefore, methylmercury production is linked to sediment mercury, which, as discussed above, is linked to mercury sources. Reducing mercury loads will reduce methylmercury production.

Mercury Accumulation in Aquatic Food Web

Methylmercury in San Francisco Bay is available for accumulation within the food web. Aquatic organisms take up methylmercury from food, water, and sediment. Higher organisms acquire methylmercury primarily through food ingestion (Rudd et al. 1983; Morel et al. 1998). Methylmercury is the predominant form of mercury found in these organisms (Morel et al. 1998). The amount of mercury that organisms contain varies considerably and does not depend solely on mercury concentrations in water. Relying exclusively on total water column mercury data can mislead efforts to assess potential methylmercury risks (Wiener et al., in press).

While the amount of methylmercury in a water body influences the rate at which methylmercury enters the food web, the structure of the food web (what eats what) determines the efficiency of transfer among organisms (Morel et al. 1998). Methylmercury has a high affinity for sulfur-containing proteins, and since upper-level consumers tend to retain the protein components of their food, tissue concentrations of mercury increase at higher levels of the food web (Mason et al. 1995). Fish assimilate about 65 to 80% of the methylmercury in their food (Wiener et al., in press). With continued exposure, methylmercury concentrations rise within aquatic organisms because elimination is typically slow relative to the rate of uptake. The relative positions of different organisms within the food web account for much of the variation in methylmercury concentrations within and among species (Wiener et al., in press).

Mercury sources are linked to the proposed fish tissue target via sediment mercury, mercury methylation, and mercury accumulation within the food web. Most modeling in support of mercury TMDLs has been based on an assumption that reducing mercury loads to the environment will have a proportional effect in reducing fish tissue concentrations (DTMC and SRWP 2002). As discussed above, factors relating to mercury methylation and accumulation within the food web are complex and not fully understood. In the absence of additional information, reductions in mercury loads are assumed, for purposes of this report, to result in proportional reductions in fish tissue residues. Additional study is needed to better quantify the relationships between mercury in San Francisco Bay sediment, methylation, and accumulation in aquatic organisms.

The San Francisco Estuary Institute is modeling striped bass growth, diet, and mercury accumulation by estimating fish growth over time as a function of energy inputs and outputs. A fish's change in size is a function of energy input due to food consumption and energy loss though metabolic processes. Pollutant uptake is a function of the rate of food consumption, pollutant concentrations in food, and assimilation rates. The model assumes the rate of predator uptake is linearly related to prey mercury concentrations, the rate of fish growth is unrelated to prey mercury concentrations, and the rate of mercury elimination is linearly related to fish concentrations. Therefore, when prey mercury concentrations are cut in half, striped bass mercury concentrations are cut in half. Preliminary model results show that striped bass mercury concentrations closely track mercury levels in prey (SFEI 2002e).

Mercury Accumulation in Birds and Wildlife

Many wildlife and bird species get essentially all of their diet from San Francisco Bay. The bay is the feeding and nesting ground for multitudes of birds, mammals, and other animals. Mercury accumulation in the aquatic food web leads to the mercury exposure of wildlife and birds that eat fish and other aquatic organisms. In birds, methylmercury readily passes from mother to eggs. When transferred to eggs, nearly 100% of the mercury is methylmercury, and about 85 to 95% is deposited in the whites of the eggs (Wiener et al., in press; CDFG 2002).

The mercury exposure of birds that catch prey throughout the bay likely reflects overall bay conditions. Birds, such as the endangered California clapper rail, that eat organisms from the bay floor often forage in sediment where methylmercury production may be high. California clapper rails are non-migratory, spending their entire lives in marshes. During the breeding season, they have a range of only a few acres and rarely move between marshes. As a result, their eggs reflect local methylmercury production (Davis et al., in press).

As discussed above, mercury sources are linked to the proposed bird egg target via mercury in sediment, methylation, accumulation within the aquatic food web, and bird exposure. Additional study is needed to quantify the relationship between the aquatic food web and bird eggs. Available information does not fully explore exposure (e.g., diet), mercury transfer to eggs, and the relationship between mercury levels in eggs and reproduction. In the absence of additional information, however, reductions in bird egg concentrations are assumed, for purposes of this report, to be proportional to reductions in fish tissue mercury. Reducing mercury loads will reduce bird egg mercury concentrations. Because birds annually eliminate much of their body burden of methylmercury through the formation of new feathers (Wiener et al., in press; CDFG 2002), mercury concentrations in adult birds would be expected to respond relatively quickly to changes in dietary mercury concentrations.

Assimilative Capacity

San Francisco Bay's capacity to assimilate mercury is the maximum amount of mercury that could be in the bay while meeting the proposed targets. Section 5, Numeric Targets, explains that a roughly 50% decrease in sediment, fish tissue, and bird egg mercury concentrations is necessary for the bay to meet water quality standards. As discussed above, reductions in sediment mercury concentrations are assumed, for purposes of this report, to result in proportional reductions in fish tissue and bird egg mercury concentrations. Since most mercury in San Francisco Bay is attached to sediment, reducing sediment mercury concentrations by 50% will reduce the total amount of mercury in San Francisco Bay by 50%.

The amount of mercury currently in San Francisco Bay can be estimated by adding up the amount of mercury in the active sediment layer (sediment where biological activity occurs) and the water column. The amount of mercury in the active sediment layer can be estimated by multiplying the average concentration of mercury in bay sediment, 0.44 ppm (SFBRWQCB 2002c), by the amount of sediment in the active layer. Assuming the active layer is about 0.15 meters deep (SFEI 2002d) and the area of the bay is about 1.3×10^9 square meters (SWRCB 2003), the volume of the active layer is about 1.9×10^8 cubic meters. Assuming the active layer is 50% water and 50% sediment, there are about 740 kilograms of dry sediment per cubic meter of volume (Weast 1981; Elert 2002). Therefore, the amount of sediment in the active layer is about 1.4×10^{11} kilograms. Using Equation 1 from Section 4, Source Assessment, the total mass of mercury in the active layer is about 63,000 kilograms.

The amount of mercury in the water column can be estimated by multiplying the average total mercury concentration in San Francisco Bay, 0.022 µg/l (SFBRWQCB 2003e), by the amount of water in the bay, 6.66×10^9 cubic meters (Conomos et al. 1985). This is about 140 kilograms, an inconsequential mass when compared to the 63,000 kilograms of mercury in the bay's active layer. Therefore, assuming that the amount of mercury in San Francisco Bay needs to be reduced by about 50% to achieve the proposed targets, the bay's assimilative capacity for mercury is about half of 63,000 kilograms, or about 32,000 kilograms.

Key Points

- Efforts to reduce mercury loads will help achieve targets and attain water quality standards because the targets are linked to the sources.
- Most mercury in San Francisco Bay is bound to sediment; reducing mercury loads will reduce sediment mercury concentrations.
- Methylmercury accumulation in aquatic organisms depends on methylmercury production and the structure of the food web.
- Reductions in sediment mercury concentrations are assumed to result in proportional reductions in fish tissue and bird egg mercury concentrations.
- Reducing net methylmercury production will further reduce mercury exposures.
- Assuming that the amount of mercury in San Francisco Bay needs to be reduced by about 50% to meet the proposed targets, the assimilative capacity of the bay is about 32,000 kilograms.

7. Allocations

This section presents recommended allocations for mercury reduction among San Francisco Bay's mercury sources. The scheme proposed below is expressed in terms of annual mercury loads (kilograms per year, kg/yr), but because bioaccumulation is a long-term process, the loads are intended to represent long-term averages and account for long-term variability.

Load and Wasteload Allocations

Allocations are divided among "wasteload allocations" for point sources and "load allocations" for nonpoint sources. The TMDL is the sum of these:

Equation 5:

$$\text{TMDL} = \text{Wasteload Allocations} + \text{Load Allocations}$$

As discussed below, the proposed allocation scheme involves an implicit margin of safety. No explicit margin of safety is proposed.

Table 7.1 presents the proposed load and wasteload allocations. For the Central Valley watershed, the Guadalupe River watershed, and urban storm water runoff, the allocations are derived from the sediment target of 0.2 ppm and the source's estimated sediment load. Assuming that sediment loads do not change, the allocations for these sources could also be expressed as a sediment mercury concentration, typically equal to or less than the proposed sediment target of 0.2 ppm. For the other sources, reasonable goals are proposed either to achieve load reductions or to maintain current loads. Some loads are assumed to be uncontrollable, at least until more information becomes available. Figure 7.1 compares current loads to the proposed allocations.

The proposed allocations are based on the assumption that the mercury from all sources is equally available to be converted to methylmercury and incorporated within the food web. However, a recent study suggests, "The input of wastewater into [San Francisco Bay's] southern reach could be both an external source of methylmercury and an important contributor to mercury methylation through the supply of organic carbon and nutrients to the system" (Conaway et al. 2003a). Evidence from chemical extraction and incubation experiments indicates that mercury in sediment from different geographic locations can differ in terms of its ability to enter the food web (CDFG 2001). Some recent mercury experiments suggest that mercury newly deposited in the environment is more readily methylated than existing mercury already in the system (Benoit et al. 2003). This suggests that, although most of the mercury in San Francisco Bay results from historical sources (Dorrance 2002; USGS 2000), recent mercury additions may be proportionally more responsible for human and wildlife mercury exposure (USGS 2003).

TABLE 7.1: Proposed Load and Wasteload Allocations

Source	Current Mercury Load (kg/yr)	Allocation (kg/yr)
Bed Erosion	460	220
Central Valley Watershed	440	330
Urban Storm Water Runoff	160	82
Guadalupe River Watershed (mining legacy)	92	2
Atmospheric Deposition	27	27
Non-Urban Storm Water Runoff	25	25
Wastewater (municipal and industrial)	19	19
Total	***1,420***	***705***

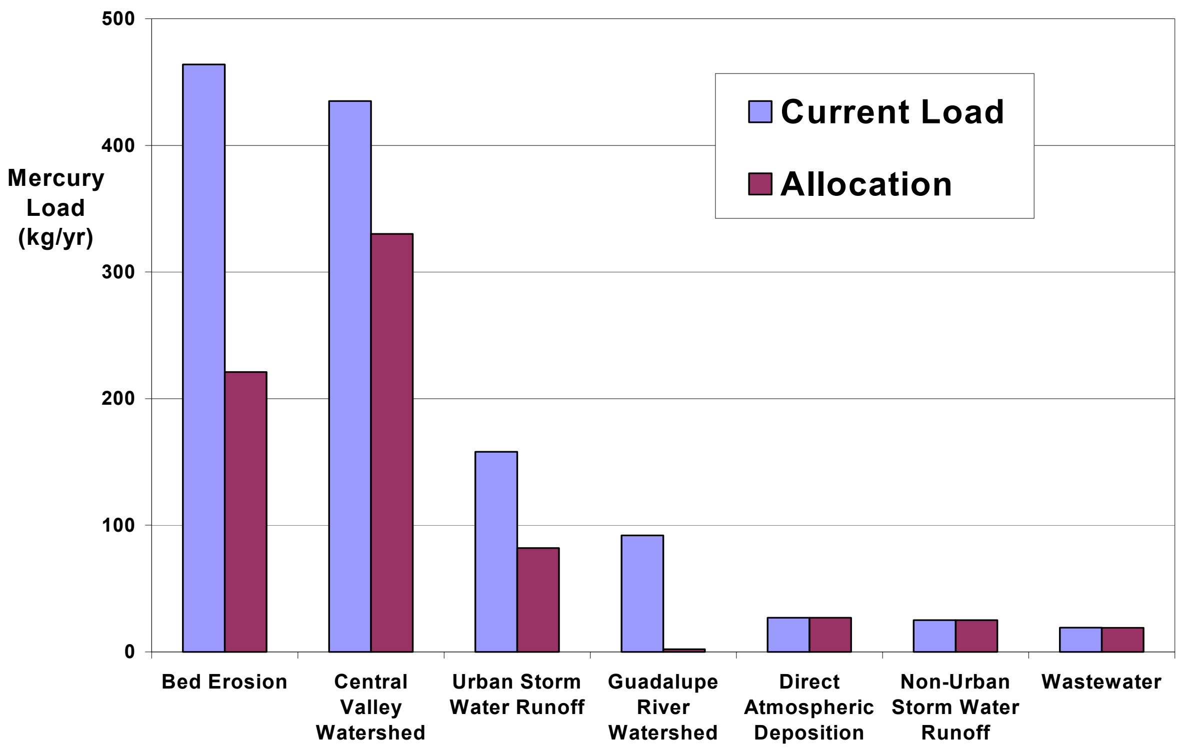

FIGURE 7.1: Current Loads and Proposed Allocations
The proposed allocations call for substantial load reductions from bed erosion, the Central Valley watershed, urban storm water runoff, and the Guadalupe River watershed.

Available information is insufficient, however, to weight the allocation scheme to account for the relative bioavailability of mercury from different sources. Therefore, these factors have not been explicitly incorporated into the proposed allocation scheme. As more information becomes available, a more refined allocation scheme may be possible. These recent studies underscore the need to consider all sources to be potentially important, even if they are relatively small compared to other sources and the amount of mercury already in the bay. Studies to address the relative bioavailability of mercury from different sources are proposed as part of the adaptive implementation plan described in Section 8, Implementation Plan.

Bed Erosion

The erosion of sediment buried below San Francisco Bay is a natural, uncontrollable process. Nevertheless, the amount of buried sediment containing elevated mercury concentrations is finite. Eventually, the mercury-laden sediment may completely erode, or alternatively, the erosive process could change such that buried mercury-laden sediment remains buried and sediment loads decline from the estimated existing 1,100 M kg/yr. In either case, a long-term reduction in mercury loads is foreseeable. This report conservatively assumes that the same amount of bed erosion will continue indefinitely. It also assumes that the mercury concentration of eroding sediment will drop to 0.2 ppm (as discussed later in this section, this is the depth-weighted average mercury concentration observed below 1.3 meters in San Pablo Bay and Grizzly Bay sediment cores [Hornberger et al. 1999]). As a result, the mercury load will eventually drop to about 220 kg/yr with or without any specific implementation measures.

Central Valley Watershed

The Central Valley watershed mercury load is estimated using Equation 1 as the product of the concentration of mercury in sediment times the amount of sediment delivered to the bay. Central Valley watershed sediment contains 0.26 ppm mercury. The Central Valley watershed sediment load is 1,650 M kg/yr. The proposed load allocation for Central Valley watershed is based on the sediment leaving this watershed meeting the proposed target of 0.2 ppm mercury and the sediment load staying the same. Multiplying 0.2 ppm times the sediment load results in a load allocation of 330 kg/yr.

Urban Storm Water Runoff

The mercury load associated with urban storm water runoff has been estimated as 160 kg/yr. The mercury in urban storm water sediment results in part from controllable urban sources, such as improperly discarded fluorescent lights, thermometers, other mercury-containing devices, and historical and ongoing industrial activities. Atmospheric deposition and natural background also contribute to the mercury in urban runoff. These contributions are assumed to be difficult to control.

Currently, the urban sediment load is estimated to be about 410 M kg/yr, and its mercury concentration is estimated to be about 0.38 ppm. The proposed allocation is based on urban storm water sediment meeting the proposed target of 0.2 ppm mercury. The proposed allocation is 82 kg/yr, which requires a reduction of 78 kg/yr from current conditions. To achieve this reduction, urban runoff management programs can reduce either sediment loads or mercury concentrations in sediment.

Under the proposed allocation scheme, urban storm water dischargers will receive a combined allocation of 82 kg/yr. Table 7.2 shows proposed individual wasteload allocations for individual urban runoff programs computed on the basis of the service area populations of each Bay Area urban runoff management program. The total population residing within the Regional Board's jurisdiction and within watersheds draining to San Francisco Bay (not the Pacific Ocean) was determined using year 2000 census data (CDF 2000) and the CALWATER 2.2 watershed boundary database (CDFFP 1999). Santa Clara, Alameda, Contra Costa, San Mateo, and San Francisco counties have countywide urban runoff management programs. Municipalities within the other counties have their own urban runoff programs. For these counties, municipalities have allocations computed based on their populations. The wasteload allocations for these counties are computed by subtracting from the total county population the populations of every municipality within that county that has an explicit load allocation. The urban runoff allocation for each municipality or county program implicitly includes any California Department of Transportation (Caltrans) or industrial facilities located in the program area that do not discharge directly to the bay.

Guadalupe River Watershed (Mining Legacy)

The source assessment estimates that of the 53 M kg/yr of sediment coming from the Guadalupe River watershed, 8.5 M kg/yr is from non-urban areas and the remainder is from urban areas. Mercury from the Guadalupe River watershed mines originates in non-urban areas and is transported by the sediment originating from non-urban areas. Applying the sediment target of 0.2 ppm mercury to this sediment load results in a load allocation of 1.7 kg/yr.

Atmospheric Deposition

Atmospheric deposition of mercury is responsible for about 82 kg/yr throughout the local San Francisco Bay watershed (not including the Central Valley) (SFEI 2001b). About 27 kg/yr of the 82 kg/yr is deposited directly on the surface of San Francisco Bay, and the remainder is deposited to the watershed and washed into the bay. The load allocation concerns only direct deposition. The load allocation is the same as the current 27 kg/yr load. This allocation is based on the assumption that atmospheric deposition is uncontrollable; however, Section 8, Implementation Plan, includes actions to address this source.

Non-Urban Storm Water Runoff

The proposed allocation for non-urban storm water runoff is the same as the current estimate of 25 kg/yr. The load was estimated using information on sediment loads and

TABLE 7.2: Proposed Wasteload Allocations for Urban Storm Water Runoff

Storm Water Program	Percent of Program Area Population	Allocation (kg/yr)	Load Reduction Required[f] (kg/yr)
Santa Clara County [a d]	27.42	23	21
Alameda County [a d]	24.68	20	19
Contra Costa County [a d]	13.53	11	10
San Mateo County [a d]	10.22	8.4	7.7
Vallejo [d]	2.00	1.6	1.5
Fairfield-Suisun [b c d]	1.92	1.6	1.5
Sonoma County [e]	0.87	0.72	0.66
Napa County [e]	0.44	0.36	0.34
Marin County [e]	0.98	0.81	0.74
Solano County [e]	0.98	0.81	0.74
San Francisco [e]	10.71	8.8	8.1
American Canyon [e]	0.17	0.14	0.13
Belvedere [e]	0.04	0.03	0.03
Benicia [e]	0.46	0.38	0.35
Calistoga [e]	0.09	0.07	0.07
Corte Madera [e]	0.16	0.13	0.12
Fairfax [e]	0.13	0.10	0.09
Larkspur [e]	0.21	0.17	0.16
Mill Valley [e]	0.23	0.19	0.18
Napa [e]	1.24	1.0	0.94
Novato [e]	0.81	0.67	0.62
Petaluma [e]	0.93	0.77	0.71
Ross [e]	0.04	0.03	0.03
San Anselmo [e]	0.21	0.17	0.16
San Rafael [e]	0.96	0.79	0.73
Sausalito [e]	0.13	0.10	0.10
Sonoma [e]	0.16	0.13	0.12
Saint Helena [e]	0.10	0.08	0.08
Tiburon [e]	0.15	0.12	0.11
Yountville [e]	0.05	0.04	0.04
Total	***100***	***82.2*** [g]	***75.8*** [g]

Source: Year 2000 census data (CDF 2000) and boundary files from CALWATER 2.2 watershed boundary data (CDFFP 1999)
[a] Because the urban runoff management programs in Alameda, Contra Costa, San Mateo, and Santa Clara counties operate under countywide permits, the municipalities within these counties are not listed individually here.
[b] The communities of Fairfield and Suisun City discharge storm water under a single storm water permit.
[c] The Fairfield-Suisun program area population was adjusted by subtracting out the population of Travis Air Force Base, estimated to be about 10,000 (BASMAA 2003).
[d] These are comprehensive Phase 1 programs.
[e] These are Phase 2 programs.
[f] This column contains the load reductions that must be demonstrated to show compliance with the load allocation (see Implementation section). However, this does not imply that, for each individual program, the specified load reduction plus the load allocation is exactly equivalent to current loading.
[g] These total may differ slightly from the column sum due to digit truncation from rounding to the appropriate number of significant digits.

mercury concentrations in sediment originating from open space. The estimated mercury sediment concentration of 0.06 ppm is well below the sediment target of 0.2 ppm and close to the estimated pre-mining background concentration of 0.08 ppm (SFBRWQCB 2003f). For this reason, no load reduction is proposed.

Wastewater

Municipal Wastewater

The proposed wasteload allocation requires that, as a group, municipal wastewater dischargers discharge no more than their current combined load of 17 kg/yr (SFBRWQCB 2003i). As a group, municipal wastewater treatment plants perform well. Additional load reductions would incur substantial costs and contribute little to the overall load reductions needed to meet the proposed targets (LWA 2002). However, municipal wastewater discharges need to be managed in such a way as to minimize the potential for methylmercury production in receiving waters and possible adverse local effects.

Table 7.3 lists individual wasteload allocations for municipal wastewater treatment plants. These allocations are computed on the basis of fractional total yearly effluent flow from each facility from 1999 through 2001. Individual wasteload allocations may be useful in identifying potentially responsible facilities if the combined allocation were ever to be exceeded.

Industrial Wastewater

The proposed wasteload allocation requires that, as a group, industrial wastewater dischargers discharge no more than their current combined load of 2.1 kg/yr (SFBRWQCB 2003i). As a group, industrial wastewater dischargers perform well. Additional load reductions would incur substantial costs and contribute little to the overall load reductions needed to meet the proposed targets (LWA 2002). However, industrial wastewater dischargers need to be managed in such a way as to minimize the potential for methylmercury production in receiving waters and possible adverse local effects.

Table 7.4 lists individual wasteload allocations for industrial dischargers. Individual wasteload allocations may be useful in identifying potentially responsible facilities if the combined allocation were ever to be exceeded. These allocations are computed on the basis of the average fraction of the current mercury load and fraction of yearly effluent volume for each industrial facility from 1999 through 2001 (Chevron 2003; SFBRWQCB 2003h). Table 7.4 includes all industrial dischargers that discharge directly to the bay. Any industrial facility that does not discharge directly to the bay is implicitly included in the urban storm water allocation for the appropriate county or municipality where the facility is located.

TABLE 7.3: Proposed Wasteload Allocations for Municipal Wastewater

Facility	Percent of Total Current Flow	Allocation (kg/yr)
American Canyon[1]	0.1	0.02
Angel Island State Park[2]	NA	NA
Benicia	0.5	0.08
Burlingame	0.7	0.12
Calistoga	0.1	0.02
Central Contra Costa Sanitary District	7.1	1.21
Central Marin Sanitation Agency	1.7	0.29
Delta Diablo Sanitation District	2.1	0.35
Dublin-San Ramon	1.7	0.29
East Bay Dischargers Authority	12.2	2.07
East Bay Municipal Utilities District	12.3	2.09
Fairfield-Suisun Sewer District	2.6	0.45
Las Gallinas Valley Sanitary District	0.6	0.10
Livermore	1.0	0.18
Marin County Sanitary District	0.1	0.02
Millbrae	0.3	0.06
Mountain View Sanitary District	0.3	0.06
Napa Sanitation District	2.0	0.33
Novato Sanitary District	0.9	0.16
Palo Alto	4.3	0.72
Petaluma	0.9	0.16
Pinole-Hercules	0.5	0.08
Port Costa Wastewater Treatment Plant[2]	NA	NA
Rodeo Sanitary District	0.1	0.02
Saint Helena	0.1	0.01
San Francisco International Airport	0.1	0.02
San Francisco, Southeast	12.5	2.13
San Jose & Santa Clara	19.0	3.23
San Mateo (city)	2.2	0.37
Sausalito-Marin City Sanitary District	0.2	0.04
Seafirth Estates[2]	NA	NA
Sewerage Agency of Southern Marin	0.6	0.10
Sonoma Valley Sanitary District	0.6	0.10
South Bayside System Authority	3.1	0.53
South San Francisco & San Bruno	1.6	0.27
Sunnyvale	2.5	0.43
Treasure Island	0.1	0.02
Vallejo Sanitation & Flood Control District	2.4	0.41
West County / Richmond[3]	2.6	0.45
Yountville	0.1	0.01

[1] American Canyon wastewater flow is approximately 1 million gallon per day (SWRCB 1999b).
[2] The data for these facilities are currently not available, but the loading is presumed to be very small.
[3] The discharger is currently investigating the monitoring information on which this facility load allocation is based to determine its representativeness. If the Regional Board determines that the data are not representative, the wasteload allocation may be adjusted during the next review in 5 to 10 years (see Section 8, Implementation Plan).

TABLE 7.4: Proposed Wasteload Allocations for Industrial Wastewater

Permit Holder	Allocation (kg/year)
Astoria Metals Corporation	NA
Bay Ship and Yacht Company	NA
C&H Sugar Co.	0.05
Cargill Salt Division, Newark Facility	NA
Cargill Salt, Redwood City	NA
Chevron	0.60
City of San Jose, Story Road Landfill	NA
ConocoPhillips	0.23
Crockett Cogeneration	NA
Dow Chemical	0.02
General Chemical[1]	0.24
GWF Power Systems 3rd Street	0.01
GWF Power Systems Nichols Road	0.01
Hanson Aggregates, Amador Street	NA
Hanson Aggregates, Olin Jones Dredge Spoils Disposal	NA
Hanson Aggregates, Tidewater Ave. Oakland	NA
Morton Salt Company, Newark	NA
Pacific Gas and Electric and East Shell Pond	NA
Pacific Gas and Electric, Hunters Point Power Plant	NA
Rhodia	0.02
San Francisco Drydock, Inc.	NA
San Francisco International Airport	0.05
Shell	0.30
Southern Energy, Pittsburg Power Plant	NA
Southern Energy, Potrero Power Plant	NA
Ultramar (Golden Eagle)	0.21
United States Navy supply center at Point Molate	NA
US Department of Defense, Point Ozol Facility (under general permit)	NA
USS-Posco	0.28
Valero	0.1

[1] General Chemical is currently investigating the monitoring information on which the wasteload allocation is based to determine its representativeness. If the Regional Board determines that the data are not representative, the wasteload allocation may be adjusted during the next review in 5 to 10 years (see Section 8, Implementation Plan).
"NA" means information for these minor facilities is not readily available from which to compute loads or allocations. Until more information becomes available, the total load from these facilities is presumed to be less than 1 kg/yr.

Other Potential Sources

Available information is insufficient to determine whether local mines or bay margin contaminated sites are sources of San Francisco Bay mercury. Therefore, no load allocations are proposed. Section 8, Implementation Plan, sets forth a strategy for evaluating these potential sources and refining the allocation scheme if appropriate.

Projected Recovery

The bay's assimilative capacity for mercury is the amount of mercury it can receive without violating water quality standards. As discussed in Section 6, Linkage Analysis, San Francisco Bay's assimilative capacity for mercury is about 32,000 kilograms. To reach the assimilative capacity, about 32,000 kilograms of mercury must be removed from the bay (50% of the existing mercury mass).

A simple model was developed to predict the effects of the proposed allocations on bay sediment mercury concentrations and the time needed to reach the sediment target (SFBRWQCB 2003g). The model is based on the steady state one-box model described in Section 3, Mass Budget Approach. The model accounts for San Francisco Bay mercury inputs and outputs, and relies on assumptions about how sources and losses will change over time. The model treats all of San Francisco Bay as essentially one large container, with mercury coming in and going out.

The model greatly simplifies the complexity of mercury movement throughout the bay, as well as foreseeable changes in sources and losses. The model assumes that bay sediment and mercury are well mixed. Each mercury atom, regardless of its form (i.e., inorganic, elemental, chemically bound, or not bound), is assumed to have an equal chance of being converted to methylmercury and entering the food web. New mercury entering the bay is treated the same as mercury already in the bay. Even with these simplifications, the model provides a useful illustration of foreseeable relative changes in sediment mercury concentrations in San Francisco Bay. Figure 7.2 illustrates the results for two scenarios evaluated.

1. *Current Loads*. In this scenario, no implementation measures are assumed. All mercury inputs (about 1,420 kilograms per year, kg/yr) remain the same throughout the simulation, with one exception. The bed erosion mercury load is assumed to decrease from 460 kg/yr to 220 kg/yr after about 110 years. The depth of the elevated mercury concentrations in Suisun Bay and San Pablo Bay sediment is about 1.3 meters (see Figure 4.3) (Hornberger et al. 1999). Suisun Bay, which is eroding more than San Pablo Bay, is eroding at a rate of about 0.012 meters per year (USGS 2001b). Therefore, the time it will take for the mercury-laden sediment to erode completely is assumed to be about 110 years. In this scenario, all mercury outputs (about 1,730 kg/yr) remain the same, except that the mercury concentration in sediment leaving through the Golden Gate is adjusted over time to account for decreasing sediment mercury concentrations throughout the bay. The result is that the average sediment mercury concentration in the bay declines from about 0.44 ppm to about 0.22 ppm over more than 200 years and never reaches the proposed sediment target.

2. *Proposed Allocations*. This scenario is like the first; however, additional load reductions of about 270 kg/yr (consistent with the proposed allocations) are phased in over 20 years. Under these conditions, the bay sediment mercury concentration declines from about 0.44 ppm to about 0.15 ppm, reaching the target of 0.2 ppm after about 120 years. Significant improvement could be observable much sooner, however. The sediment mercury concentration could decline to about 0.3 ppm after about 40 years. This 30% reduction could significantly reduce the risks mercury poses to humans and wildlife, including rare and endangered species.

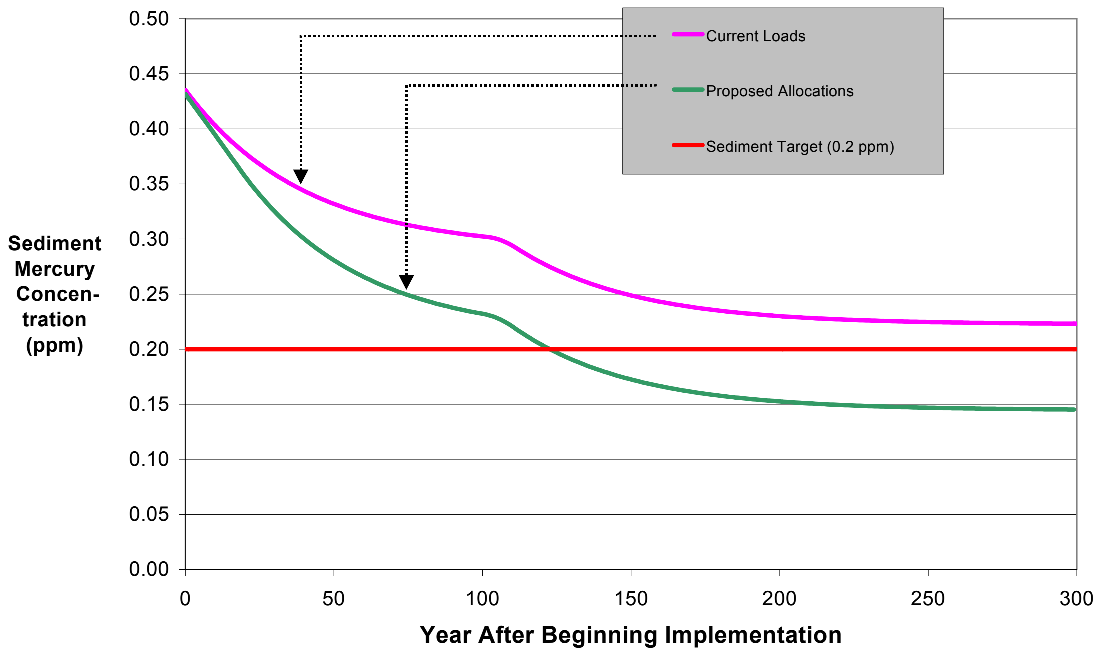

FIGURE 7.2: Model Results
A simple model was used to estimate changes in average sediment mercury concentrations under two scenarios: (1) current loads and (2) proposed allocations.

Margin of Safety

Uncertainties associated with TMDL analyses must be incorporated as a margin of safety. The margin of safety is to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality. The purpose of the margin of safety is to ensure, in the face of uncertainties, that the targets and water quality standards will be met.

The margin of safety can be derived either explicitly or implicitly. Providing an explicit margin of safety would involve reserving a specific mercury load allocation for the margin of safety. Alternatively, an implicit margin of safety involves using conservative assumptions (assumptions more likely to be over-protective than under-protective) throughout the analysis. This report relies on conservative assumptions to propose targets and allocations, and thereby provides the margin of safety implicitly. The proposed adaptive implementation strategy described in Section 8, Implementation Plan, offer an additional margin of safety. The proposed plan involves measuring progress toward meeting the proposed targets and, as necessary, re-evaluating the validity and appropriateness of the assumptions underlying the analysis. Implementation actions will be revised as new information becomes available.

Conservatism in Targets

The assimilative capacity and the mercury reductions that the allocations entail are derived from the reductions needed to meet the proposed targets. In developing the targets, several conservative assumptions were made:

- Local fish consumption data are used. Using the 95th percentile of local consumption (not including the vast majority of Bay Area residents that do not eat bay fish) reduced the fish tissue target from U.S. EPA's fish tissue residue criterion. In contrast, U.S. EPA used the 90th percentile of national consumption estimates and included data for non-consumers (U.S. EPA 2001). As a result, the fish tissue target is one third less than the U.S. EPA criterion.

- The method U.S. EPA used to develop its fish tissue criterion (upon which the fish tissue target is derived) includes several conservative assumptions, including the incorporation of a factor of 10 in the reference dose to account for uncertainties related to mercury's health effects and its metabolism within the body. The fish tissue target reflects a conservative estimate of the lifetime daily exposure level at which no adverse effects would be expected (U.S. EPA 2001).

- To protect wildlife from toxicity caused by mercury taken up through the aquatic food web, U.S. EPA calculated a wildlife criteria for mercury in fish tissue (U.S. EPA 1997c). These criteria are 0.077 ppm for small fish and 0.35 ppm for larger, predator fish. The fish tissue target proposed to protect human health, 0.2 ppm, is on roughly the same order of magnitude.

- The bird egg target is intended to protect the most sensitive wildlife endpoint and the most sensitive resident birds (CDFG 2002). The bird egg target will be refined as more information becomes available. The goal of "no detrimental increase in mercury concentrations in San Francisco Bay bird eggs" is conservative.

- The sediment target is conservative because it is derived from the fish tissue and bird egg targets, which are conservative, and is consistent with water quality objectives.

Conservatism in Allocations and Implementation

Achieving the proposed allocations will reduce mercury bioaccumulation in fish and wildlife. The adaptive implementation strategy described in Section 8, Implementation Plan, calls for some additional actions to reduce mercury in fish and wildlife. For example, it calls for investigating ways to control atmospheric deposition, even though the allocation scheme does not assume specific load reductions. To the extent that atmospheric deposition can be controlled, all watershed sources will be reduced. The implementation plan also calls for investigating ways to control mercury methylation. To the extent that methylmercury production can be controlled or managed, the proposed targets will be met more quickly, reducing mercury concentrations in fish tissue and bird eggs.

Although this report provides an implicit, rather than an explicit, margin of safety, Figure 7.2 demonstrates that this analysis is sufficiently conservative. The proposed load and wasteload allocations will result in an average sediment mercury concentration of about 0.15 ppm, which is 0.05 ppm below the proposed target of 0.2 ppm.

Seasonal Variability and Critical Conditions

Federal regulations require TMDLs to account for seasonal variations and critical conditions (e.g., stream flows, pollutant loads, or other parameters). Mercury contamination in San Francisco Bay does not appear to be worse at one time of year versus another (as would be the case, for example, for oxygen depletion in a lake during summer months). Therefore, concern about seasonal variability is not critical to this analysis or implementation, and the proposed allocation scheme does not have a seasonal component.

However, there is substantial inter-annual variability in the amount of Bay Area rainfall (SFEI 2003b), and variability in rainfall means the amount of sediment and water delivered from tributaries will vary among years. Furthermore, rainfall variability affects the amount of water that infiltrates into wastewater collection systems. Increases in the volume of water or mass of sediment delivered could increase the amount of mercury delivered to the bay. The proposed load and wasteload allocations are long-term annual loads. Section 8, Implementation Plan, acknowledges and accommodates long-term inter-annual variability by evaluating whether sources are meeting allocations on a multi-year basis. Long-term averaging will help smooth out differences among high and low rainfall years.

Key Points

- To reach the proposed sediment target and attain water quality standards, the proposed load and wasteload allocations are as follows: bed erosion, 220 kg/yr; Central Valley watershed, 330 kg/yr; urban storm water runoff, 82 kg/yr; Guadalupe River watershed (mining legacy), 2 kg/yr; atmospheric deposition, 27 kg/yr; non-urban storm water, 25 kg/yr; and wastewater, 19 kg/yr.
- The proposed allocation scheme is based on the assumption that mercury from all sources is similarly available to be converted to methylmercury and taken up into the food web.
- By implementing the proposed allocations, the average sediment mercury concentration in the bay will likely drop from about 0.44 ppm to about 0.15 ppm, reaching the target of 0.2 ppm after at least 120 years.
- Conservative assumptions used to develop the proposed numeric targets and allocations provide an implicit margin of safety.

8. Implementation Plan

This section describes the plan to implement the load and wasteload allocations specified in the previous section. This plan addresses all of the sources for which there is an explicit load allocation as well as other entities relevant to mercury management in the bay.

Objectives

This proposed implementation plan has four principal objectives. The first is to reduce existing and future discharges of mercury to San Francisco Bay that are due to controllable water quality factors. The goal of such reductions is to attain the proposed load allocations and wasteload allocations and numeric targets. Meeting the allocations and targets will result in attainment of applicable water quality standards. Not all mercury discharges are due to controllable factors, and controllable discharges cannot necessarily be controlled with 100% effectiveness. In developing implementation actions for various sources, this plan takes into consideration the relative magnitude of the source, quantity and quality of data on which source estimate is based, and the feasibility and cost of control.

In addition to controlling mercury loads, a second objective of the implementation plan is to reduce the amount of mercury transformed to methylmercury, the most toxic form of mercury and the form most readily available for uptake by organisms. Based on the discussion presented in Section 6, Linkage Analysis, intervention is possible at two points along the linkage between sources and targets. One point of intervention is the reduction of sources of mercury to San Francisco Bay. The second point of intervention is the reduction of the amount of mercury that is transformed to methylmercury. Improving our understanding and control of methylation will be important if load reduction efforts are to be effective. Controlling methylation should also guard against locally enhanced biological uptake near discharge locations.

A third objective of this implementation plan is to improve our technical understanding of mercury in San Francisco Bay and source control effectiveness, and then use this information to guide future decisions. Although available data are sufficient to support the TMDL analysis and implementation plan, an adaptive approach is proposed for implementation of the TMDL. This approach consists of: a program of immediate actions to control known sources of mercury with high potential for reduction; a program of monitoring to determine progress toward targets and effectiveness of early actions; special studies to refine our understanding of mercury fate and effects; and a scheme to adapt the strategy in the future as new information becomes available. The actions to be taken immediately are described first, followed by the manner and timeframe for obtaining, reviewing and incorporating information.

A fourth objective arises from the recognition that water quality programs are most efficient when they address more than one pollutant. Therefore, to the extent possible, this plan seeks to encourage implementation actions that reduce loads of multiple pollutants and not mercury alone.

This implementation plan proposes actions to reduce mercury loads and mercury methylation and suggests monitoring needs, where appropriate, for each mercury source.

Implementation Actions

Central Valley Watershed

Existing Load:	**440 kg/yr**
Allocation:	**330 kg/yr**
Required Actions:	**Develop and implement San Francisco Bay Delta and Central Valley Tributary mercury TMDLs**

The Central Valley Regional Water Quality Control Board (Central Valley Regional Board) is in the process of developing mercury TMDLs for the San Francisco Bay Delta and mercury-impaired tributaries (Cache Creek, Harley Gulch, Sulphur Creek, Bear Creek, and Sacramento River). Load allocations have not yet been established for those TMDLs, but the Central Valley Regional Board's targets will be consistent with those employed in San Francisco Bay, and the load reductions necessary to achieve their targets and applicable water quality standards will likely reduce Central Valley watershed loads to San Francisco Bay sufficiently to meet the requirements of the San Francisco Bay TMDL.

The five-year average Central Valley watershed mercury load is proposed to assess compliance with the allocation. A minimum averaging period of five years is needed to account for the region's substantial inter-annual rainfall variability, which affects the quantity of sediment and mass of mercury delivered (SFEI 2003b). The load allocation will be assessed as the five-year average of the product of the flow-weighted sediment mercury concentration and the sediment load. If sediment load estimates are unavailable, the default will be the value of 1,650 million kilograms per year used in Section 4, Source Assessment. The Mallard Island monitoring station located just inside the San Francisco Bay Regional Board's jurisdiction will be used to evaluate mercury loads. However, this location may be subject to confounding physical processes in which mercury-laden Suisun or Grizzly Bay sediment is transported upstream by incoming tides and transported downstream again past Mallard Island. We (San Francisco Bay Regional Water Quality Control Board staff) intend to work with the Central Valley Regional Board to refine this source estimate.

Implementation actions likely to be employed in the Central Valley watershed include mine remediation and targeted sediment capture. Other actions may be similar to those outlined for the bay in this report. The benefit of control efforts may be difficult to detect and slow to manifest because of the size of this watershed and the distribution of mercury sources. As such, we propose to implement the allocation in phases using an interim 10 year mercury loading milestone of 385 kilograms per year (kg/yr), which is halfway between the current load and the allocation.

Urban Storm Water Runoff

Existing Load:	**160 kg/yr**
Allocation:	**82 kg/yr**
Required Actions:	**Comply with NPDES permits, implement pollution prevention and control programs, evaluate mercury bioavailability of discharge and feasibility of minimizing mercury uptake into the food web**

This allocation will be implemented through the National Pollutant Discharge Elimination System (NPDES) storm water permits issued to storm water management agencies and the California Department of Transportation (Caltrans). Storm water management agencies can reduce urban mercury loads by preventing urban mercury sources from enriching sediment or by reducing the amount of enriched sediment discharged to the bay. Storm water management agencies can prevent enrichment through various source control and pollution prevention activities, including fluorescent light bulb and thermometer collection and disposal programs, and other household hazardous waste collection programs. In addition, urban storm water mercury loads can be reduced through capture, detention, and removal of highly contaminated sediment, and possibly by urban storm water treatment. Substantial infrastructure improvements are expected to result from implementation of construction and new development runoff permit requirements. These requirements, which promote controls such as planting vegetative buffers around impervious surfaces, may effectively control urban sediment discharges. Many of these actions have the potential benefit of reducing other particle-associated pollutant loads in addition to mercury.

The proposed plan would recognize load avoided by implementing pollution prevention and control programs as credit toward attaining the TMDL allocation. Therefore, the benefit of these measures needs to be carefully quantified.

How rapidly watershed loads and sediment concentrations will respond to control efforts is unknown. Detectable effects will likely lag source control efforts by several years as mercury bound to particulates can be stored in stream beds, banks and floodplains for several years, particularly during drought years (SFEI 2003b). As such, we propose to implement the allocation in phases using an interim 10-year mercury loading milestone for this source category of 120 kilograms per year (kg/yr), which is halfway between the current load and the allocation.

Loads avoided by diverting urban storm water, otherwise destined for San Francisco Bay, to treatment facilities will also be recognized as credit toward attaining the allocation. If this is accomplished with the assistance of wastewater treatment facilities, credit for mercury loads avoided may be shared by cooperating agencies. In addition, if storm water dischargers help to reduce loads from another source category (e.g., mining legacies), credit for loads avoided can be shared by the cooperating entities.

This plan proposes incorporating the requirements listed below into NPDES urban runoff program (storm water) permits for entities conducting comprehensive control programs (phase 1 programs in Table 7-2). Similar requirements will be put in place five years after TMDL adoption for phase 2 programs. We propose that these elements will be implemented through the Regional Board authorities provided by the NPDES General Permit for Storm Water Discharges from Small Municipal Separate Storm Sewer Systems issued by the State Board.

The proposed requirements are:

- Using existing data, evaluate whether any sources or locations with elevated mercury concentrations exist within each jurisdictional area;
- Develop and implement a mercury source control program;
- Develop and implement a monitoring system for quantifying mercury loads or the loads avoided via source control efforts;
- Provide support for studies aimed at better understanding the bioavailability of mercury sources, and mercury fate, transport, and biological uptake in San Francisco Bay; and
- Prepare an annual report that documents and assesses mercury loads or loads avoided and ongoing pollution prevention and control activities.

Within the jurisdiction of each storm water entity, Caltrans manages and is responsible for discharges associated with California highways and related facilities. The percentage of each storm water management agencies' jurisdictional area's mercury load that Caltrans should be responsible for, and the reductions needed from Caltrans runoff have not been determined. Caltrans currently contributes 10% of the Bay Area Storm Water Management Agencies fees for the Regional Monitoring Program for Trace Substances. This percentage may be appropriate for load allocations as well, and it is recommended that urban storm water management agencies and Caltrans work together to determine an equitable way to share each allocation.

We also recognize that each urban storm water allocation implicitly includes discharges from industrial and construction sites within municipalities. Municipalities have a responsibility to oversee these sources. However, if it is determined that a source is substantially contributing to mercury loads to the bay, and/or it is outside the jurisdiction or authority of a municipality, we will present source specific NPDES permit options for Regional Board consideration.

We recommend that the following proposed elements should be incorporated into the regional work plan for the San Francisco region required by Caltrans's statewide NPDES permit issued by the State Board and reported to the San Francisco Bay Regional Board:

- Develop and implement a monitoring system for quantifying mercury loads or loads avoided via source control efforts;
- Prepare an annual report that documents and assesses mercury loads or loads avoided and ongoing source control activities; and
- Develop an equitable allocation-sharing scheme among urban storm water management agencies.

We recommend that the urban storm water management agencies and Caltrans demonstrate compliance with allocations using one of the methods listed below. We recommend that a five-year averaging period be used to evaluate compliance. A 5-year averaging period is needed to account for the substantial inter-annual rainfall variability, and resultant quantity of sediment and mass of mercury delivered.

1. Quantify the five-year average of new mercury loads avoided through pollution prevention, source control, and treatment efforts. New mercury loads avoided need to be distinguished from those currently being avoided because the benefit of existing control programs is accounted for in the baseline load estimates on which the allocations are based. The new mercury loads avoided will be compared to the amounts necessary to achieve the load allocation.
2. Quantify the five-year average load using flow data and water and suspended particulate mercury concentration data. This five-year load estimate will be compared to the allocations.
3. Quantitatively demonstrate that sediment discharges from program area are below the 0.2 parts per million (ppm) target.

Guadalupe River Watershed (Mining Legacy)

Existing Load:	**92 kg/yr**
Allocation:	**1.7 kg/yr**
Required Actions:	**Develop and implement the Mercury TMDL in the Guadalupe River Watershed**

The Guadalupe River Watershed mercury TMDL is the primary regulatory vehicle for achieving water quality goals in the watershed and reducing loads to the bay. The implementation plan for the Guadalupe River Watershed Mercury TMDL will address the first three of the four implementation objectives for the bay: to reduce existing and future controllable discharges of total mercury, to reduce the amount of mercury transformed to methylmercury, and to refine our understanding of load estimates and methylation. Implementation measures will likely include mining waste removal actions and extensive slope stabilization measures in the New Almaden Mining District (a steeply sloped upper watershed area); creek restoration activities throughout the watershed, including removal of overbank mining waste deposits; removal of accumulated sediment from surface water conveyance facilities (which will likely reduce loads to the bay of multiple pollutants in accumulated sediment); a monitoring program to evaluate methylation controls; methylation control measures in reservoirs and possibly in other portions of the watershed; and monitoring programs to refine our understanding of sources and effects.

Control efforts will not be implemented immediately, and the benefit of control efforts may be difficult to detect and slow to manifest because of the size of the watershed and the distribution of mercury sources within the watershed. As such, we propose to implement the allocation in phases using an interim 10-year mercury loading milestone for this source category of 47 kilograms per year (kg/yr), which is halfway between the current load and the allocation.

The Guadalupe River Watershed Mercury TMDL is being developed via a collaborative process between the Santa Clara Valley Water District and the San Francisco Bay Regional Board, with active stakeholder involvement. The Santa Clara Valley Water District and the Regional Board signed a Memorandum of Understanding in Spring 2003 that describes the scope, schedule, and collaborative process for TMDL development. For the purpose of the mercury TMDL for San Francisco Bay, assessing progress toward reducing mercury loads is critical. Therefore, the adaptive management requirements for the Guadalupe River Watershed center on periodic loading studies to assess progress toward achieving the targets and load allocation.

Atmospheric Deposition

Existing Load:	**27 kg/yr**
Allocation:	**27 kg/yr**
Required Actions:	**Support and track national efforts such as the Clear Skies Act and the Quicksilver Caucus**

In view of the degree to which uncontrollable sources appear to dominate Bay Area air concentrations and presumably deposition, load reductions do not appear feasible at this time. A key management issue to be resolved through the adaptive approach to implementing the TMDL is determining the significance of atmospheric deposition and potential pollution prevention and source control options, especially for local sources.

Estimating the local contribution to atmospheric deposition is difficult. Mercury can be transported long distances in the atmosphere, and the Bay Area is downwind of heavily industrialized countries in Asia. In 1996, the California Air Resources Board estimated that Bay Area mercury emissions total about 500 kg/yr (Tetra Tech 2002). Coal combustion in China accounts for about 10% of the global anthropogenic contribution of mercury to the atmosphere, and the United States' contribution is about 5% of the global total (Steding and Flegal 2002). Although it is not known exactly how much of this mercury is deposited locally, air concentration modeling can provide a starting point to estimate such contributions.

The **RE**gional **L**agrangian **M**odel of **A**ir **P**ollution (RELMAP) mercury model was developed to simulate the emission, transport, dispersion, atmospheric chemistry, and deposition of mercury across the continental United States. This model was used in the development of the Mercury Study Report to Congress to estimate the magnitude and pattern of mercury deposition throughout the United States from domestic emissions and from the global average concentration of elemental mercury from sources around the world (U.S. EPA 1997a). The results of this modeling effort for the counties in the San Francisco Bay region are shown in the table below. As shown in the table, the modeled local contribution represents a substantial portion (ranges from 10% to 59%) of the total average air concentration. The mass of mercury deposited is proportional to the air concentration.

TABLE 8.1: Modeled Local Source and Background Contributions to Bay Area Mercury Concentrations in Air (ng/m^3)

County	Average Air Concentration	Local Source Contribution	Background Contribution
Alameda	2.26	0.76	1.5
Contra Costa	1.81	0.31	1.5
Marin	1.68	0.18	1.5
Napa	1.70	0.20	1.5
San Francisco	3.66	2.16	1.5
San Mateo	1.92	0.42	1.5
Santa Clara	1.89	0.39	1.5
Solano	1.67	0.17	1.5
Sonoma	2.00	0.50	1.5

ng/m^3, nanograms per cubic meter
Source: Tetra Tech 2003

The cement industry is likely the largest stationary air source in the Bay Area (Tetra Tech 2002). U.S. EPA studied the cement industry and determined that such treatment would not be cost effective (BAAQMD 2003). Reducing mercury from cement kilns requires a pretreatment step involving carbon adsorption. Costly carbon treatment is probably the most effective option for reducing mercury emissions because existing controls involving cooling exhaust gases do not readily control mercury emissions.

Crematoria emit mercury into the air from dental fillings. The Bay Area Air Quality Management District estimated crematoria emissions to be about 12.2 kg/yr (BAAQMD 2000). Crematoria permits focus on clean combustion and do not consider mercury. The American Dental Association has reported a 30% decrease in the number of mercury amalgam fillings used between 1990 and 1999 (Berthold 2002). If this trend continues, crematoria emissions will likely decrease proportionally.

National mercury reduction efforts are underway. The Great Lakes Binational Toxics Strategy (Environment Canada and U.S. EPA 1997) calls on the United States to reduce by 50% its anthropogenic mercury inputs to the atmosphere by 2006. However, it is difficult to predict whether reduction efforts within the United States and Canada, along with reductions in local sources, will offset potential increases from combustion sources in Asia. The United States Congress is currently considering the Clear Skies Act of 2003. If passed, it would cut mercury emissions by 69 percent (from 1999 levels) by establishing a cap of 15 tons of mercury emissions (from power plants) by 2018 (U.S. EPA 2003). The Quicksilver Caucus was formed in May 2001 by a coalition of state environmental associations to develop comprehensive approaches for reducing mercury in the environment and is currently engaged in two interrelated efforts. In partnership with U.S. EPA, the Quicksilver Caucus is developing a mercury stewardship program to identify best management practices for management, handling, and storage of mercury, and assess market policy options and review mercury commodity markets with a view toward limiting mercury in the marketplace. A second effort of the caucus is to define a national strategy to achieve reduction in mercury loads to surface waters to attain water quality standards (ECOS 2003a 2003b).

There is emerging evidence that mercury newly deposited from the atmosphere may be more available for biological uptake than mercury already present in an aquatic system (USGS 2003; Benoit et al. 2003). Chemical extraction and incubation experiments suggest that mercury-containing sediment from different geographic locations can differ substantially both in its chemical availability and potential to produce methylmercury (CDFG 2001). Therefore, mercury entering the bay from atmospheric deposition could be more available for methylation and biological uptake than mercury derived from legacy sources, such as mining operations.

The priorities for the adaptive implementation plan are refining the atmospheric deposition load estimate, assessing the contribution and controllability of local sources, and investigating the relative availability of deposited mercury for methylation and biological uptake.

Wastewater

Municipal Discharges

Existing Load:	**17 kg/yr**
Allocation:	**17 kg/yr (group total to be implemented)**
Required Actions:	**Comply with NPDES permits, implement pollution prevention programs to assure no net increase in load, evaluate mercury bioavailability of discharge and feasibility of minimizing mercury uptake into the food web**

Individual wasteload allocations have been calculated for each municipal wastewater discharge. We propose to implement the total wasteload allocation as a group mass limit equivalent to the sum of the individual wasteload allocations. Since the NPDES permits will explicitly prohibit the aggregate municipal wastewater mercury load from exceeding the group allocation of 17 kg/yr, this mass limit is explicitly consistent with the TMDL allocation. We propose to evaluate compliance with the group mass limit every five years (typical NPDES permit cycle) by comparing the five-year average annual load from all publicly owned treatment works (POTWs) to the mass limit. The annual load is defined as the sum of the annual loads for each POTW, which in turn are defined as the sums of their monthly loads. If the five-year average annual load exceeds the group mass limit, the Regional Board will consider a range of enforcement options and implementation of facility-specific mass limits. We propose that enforcement action be directed against only those facilities that exceeded their individual wasteload allocation as given in Section 7, Allocations.

To ensure that POTWs continue to operate at a high performance level and that sensible pollution prevention and source control efforts are maintained, performance-based monthly average and daily maximum effluent concentration triggers are proposed. There are two broad categories of POTWs – facilities that provide secondary treatment, and those that provide advanced treatment. Facilities providing advanced treatment have better performance, hence lower effluent concentrations than those providing secondary treatment so the trigger levels for advanced facilities are lower than those for secondary treatment facilities. The proposed trigger values for secondary treatment facilities are: daily maximum of 0.065 µg/l total mercury (derived from the 99th percentile concentration of effluent data collected from January 2000 to September 2002) and monthly average of 0.041 µg/l total mercury (derived from the 95th percentile concentration of effluent data collected from January 2000 to September 2002) (SFBRWQCB 2002a). For POTWs providing advanced treatment, the proposed triggers are: daily maximum of 0.021 µg/l total mercury (the 99th percentile concentration) and a monthly average of 0.011 µg/l total mercury (the 95th percentile concentration). The following actions are proposed requirements if triggers are exceeded:

- Evaluate the cause of the exceedance;
- Evaluate the effectiveness of existing pollution prevention programs and methods for preventing future exceedances;
- Evaluate feasibility and effectiveness of technology enhancements to improve plant performance; and
- Evaluate whether the existing monitoring program is adequate for detecting potential exceedances.

The potential availability of POTW discharged mercury for methylation and biological uptake, and possible local effects of such discharges, are not well understood. We proposed that dischargers undertake studies to evaluate local impacts and bioavailability. If evidence of local effects from POTW effluent is discovered, or if POTWs significantly contribute to mercury concentrations in the food web, the Regional Board may impose discharge restrictions aimed at minimizing or avoiding adverse impacts. In order to facilitate implementation and tracking of this and other TMDL efforts, we will strongly encourage municipal dischargers to participate in the Electronic Reporting System already in place for the Regional Board. We also will strongly encourage expansion of water re-use programs because such programs result not only in conservation of water resources, but they also result in reduced loads to the bay of mercury and other pollutants as well. We propose that the following requirements be incorporated into NPDES permits for municipal wastewater dischargers:

- Develop and implement effective mercury source control programs to minimize significant mercury sources (level of effort will be commensurate with the discharge volume of the facility);
- Develop and implement a monitoring system to track individual and aggregate wastewater loads and the status of source control/pollution prevention activities;
- Provide support for studies aimed at better understanding the bioavailability of mercury from different sources, and mercury fate, transport, and biological uptake in San Francisco Bay;
- Investigate the potential for local effects in the vicinity of wastewater discharges; and
- Prepare a single annual report that documents and assesses mercury load data from all facilities, mercury effluent concentrations, and ongoing source control activities, including avoided mercury loads.

Industrial Discharges, including Petroleum Refineries

Existing Load:	**2.1 kg/yr (major dischargers), < 1 kg/yr (minor dischargers)**
Allocation:	**2.1 kg/yr (major dischargers), < 1 kg/yr (minor dischargers)**
Required Actions:	**Compliance with NPDES permits, evaluate mercury bioavailability of discharge and feasibility of minimizing mercury uptake into the food web, pollution prevention**

These wasteload allocations will be implemented through NPDES permits. The attainment of the individual mass limits will be evaluated every five years by comparing the five-year average annual load to the mass limit. The yearly load is defined as the sum of the monthly loads from each facility. If the five-year average annual load exceeds the mass limit, the Regional Board will consider financial penalties.

To ensure that industrial facilities continue to operate at a high performance level and that sensible pollution prevention and source control efforts are maintained, each industrial discharger will be assigned performance-based effluent triggers for the monthly average and daily maximum mercury concentration in its effluent. All NPDES permits will contain provisions that specify required actions if concentration-based trigger values are exceeded. These triggers will be as follows: daily maximum 0.062 µg/l total mercury (derived from the 99th percentile concentration of effluent data collected from January 2000 to September 2002) and monthly average of 0.037 µg/l total mercury (derived from the 95th percentile concentration of effluent data collected from January 2000 to

September 2002) (SFBRWQCB 2003a). The following actions will be required if triggers are exceeded:

- Evaluate the cause of the exceedance;
- Evaluate the effectiveness of existing pollution prevention programs and methods for preventing future exceedances;
- Evaluate feasibility and effectiveness of technology enhancements to improve plant performance; and
- Evaluate whether the existing monitoring program is adequate for detecting potential exceedances.

The potential availability of mercury in industrial wastewater for methylation and biological uptake, and possible local effects of such discharges, are not well understood. We propose that dischargers will be required to undertake studies to evaluate localized impacts and bioavailability. If evidence of local effects from industrial effluent is discovered, or if industrial dischargers significantly contribute to mercury concentrations in the food web, the Regional Board may impose discharge restrictions aimed at minimizing or avoiding adverse impacts. To facilitate implementation and tracking of this and other TMDL efforts, we will strongly encourage dischargers of this category to participate in the Electronic Reporting System already in place for the Regional Board.

We propose that the following requirements be incorporated into NPDES permits for industrial wastewater dischargers:

- Develop and implement effective mercury source control programs to minimize significant mercury sources (level of effort will be commensurate with the discharge volume of the facility);
- Provide support for studies aimed at better understanding the bioavailability of mercury sources, and mercury fate, transport, and biological uptake in San Francisco Bay;
- Investigate the potential for localized effects in the vicinity of industrial discharges; and
- Prepare an annual report that documents mercury load data and source control/pollution prevention activities.

The fate of mercury originally contained in crude oil as it goes through the refining process is not well understood. This mercury may be emitted directly to the air from the refinery, in refinery product, in wastewater, or in solid waste (Wilhelm 2001). The amount of mercury Bay Area processed refinery crude oil is about 400 kg/yr (SFBRWQCB 2003k; CEC 2002; CARB 2001; NHTSA 2001). Based on refinery wastewater monitoring data, a very small amount of this mercury (less than 0.5 kg/yr) is discharged in wastewater effluent (SFBRWQCB 2003a).

Air emissions from refineries could be depositing locally on the bay surface and surrounding watershed such that the wastewater contribution from refineries calculated for this report understates the impact these facilities have on bay mercury concentrations.

We propose that refineries evaluate the significance of their atmospheric emissions within five years. Two key questions need to answered:

1. How much mercury is in Bay Area refined crude oil? Previous estimates show that the mercury concentration in crude oil is variable enough that it is important to look into this issue (Wilhelm 2001).
2. After the refining process, what is the fate of the mercury originally contained in crude oil?

Watershed Approach

A watershed approach could be helpful in managing pollutant loads, particularly if net environmental benefits can be realized. Such an approach could involve urban storm water management programs, wastewater facilities, and other responsible parties in a watershed accepting joint responsibility for load reductions. Trading pollution credits outside the watershed may also be possible. However, no such program currently exists. Interested parties may submit detailed proposals for such an approach, including recommendations for establishing appropriate credit for straightforward load reduction activities like treatment and water re-use and for more difficult-to-quantify activities that result in reduced mercury loads (e.g., collection of household hazardous waste containing mercury). An acceptable credit program may include incentives for agencies to implement load reduction activities and account for avoided mercury loads. Credits could be used to offset annual loads and attain allocations for multiple sources. The relative bioavailability of mercury from different sources and the potential for local impacts must be considered.

Other Potential Sources

Existing Load:	**Unknown**
Allocation:	**To be determined, if necessary**
Required Actions:	**Identify and quantify sources, implement mercury and methylmercury control measures as appropriate.**

Section 4, Source Assessment, identifies potential sources for which mercury loads are unknown, including potential contributions from mercury mines other than those in the Guadalupe River and Central Valley watersheds, industrial and military sites along the bay margins that are contaminated by mercury. Wetlands also produce methylmercury, although they are not sources of new inorganic mercury to San Francisco Bay. These potential sources are addressed below.

Mercury Mines

To address mercury mines requires continued implementation of the Mines and Mineral Producers Discharge Control Program described in the Basin Plan. The key regulatory component of this established program is that property owners of inactive and active mine sites are required to comply with NPDES industrial storm water regulations. Under this program, the Regional Board has the authority to issue individual industrial permits or allow the discharger to obtain coverage under the industrial storm water general permit issued by the State Water Resources Control Board.

Approximately seven small mercury mines located in the North Bay are not meeting the conditions set forth in the Basin Plan. Responsible parties will be notified of their requirements to do so. Regional Board staff will work with each mine site/property owner to determine the details and sufficiency of monitoring, and necessary source control actions.

Bay Margin Contaminated Sites

A number of former industrial and military sites that contain mercury-enriched sediment surround the bay. While some data are available to estimate the amount of mercury at these sites, loads from these locations are unknown. Without load information, it is impossible to allocate a load. While the load these sites contribute to the bay may be small relative to other known sources, these sites may pose a significant threat if biological uptake is taking place in these areas. As such, cleanup of these contaminated sites is a Regional Board priority and many cleanups are underway. The Regional Board's approach to cleanup of contaminated sites is detailed in the Basin Plan. This report does not propose imposing new cleanup standards for these sites. However, the TMDL implementation plan will require responsible parties to assess risks to the bay's ecosystem, evaluate local effects on humans and wildlife, and consider mercury TMDL wildlife and sediment targets when determining site cleanup goals. In particular, we propose that responsible parties will be required to do the following:

1. Quantify mercury mass on site to within about ±20%;
2. Quantify annual total and methylmercury loads to the bay; and
3. Assess local impacts on human health and wildlife.

The details of monitoring programs to address these information needs will need to take into account site-specific features of the site. We will work with the responsible parties to determine the sufficiency of the monitoring and data collection efforts.

Wetlands

Although wetlands are not a source of inorganic mercury to the bay, they may contribute substantially to methylmercury production and biological exposure within the bay. Plans for extensive restoration of wetlands in San Francisco Bay region raise the concern that mercury methylation may increase, thereby increasing the amount of mercury entering the food web (LFR 2002). Implementation tasks related to wetlands focus on managing existing wetlands and constructing new wetlands such that methylmercury production and subsequent transfer to the food web are minimized.

How and where methylation takes place in wetlands and the significance of wetland methylmercury production to the mercury observed in fish and wildlife are unknown. An improved understanding of factors that control methylmercury production and biological uptake is needed as the wetlands restoration projects move forward. The Basin Plan details the Regional Board's regulatory authority and programs aimed at restoring and protecting wetlands. The Regional Board routinely issues Waste Discharge Requirements or Clean Water Act Section 401 certifications that set forth conditions related to the fill or construction and management of wetlands.

To implement the mercury TMDL, we propose requirements for wetland projects will include provisions that the restored region be designed and operated to minimize methylmercury production and biological uptake, and result in no net increase in mercury or methylmercury loads to the bay. We propose pre- and post-restoration monitoring requirements to demonstrate compliance. For managed wetland areas not subject to permit requirements, we will evaluate ways to encourage management to meet the objectives of this TMDL.

The Regional Board will support and promote projects and studies aimed at evaluating methods to minimize mercury methylation in new and existing wetlands. The following list of wetland design and management options suggests the types of studies or pilot projects needed.

- **Pretreatment** – Capture and detention of mercury-laden sediment prior to transport into wetlands.
- **Sediment cover requirements** – If wetlands are constructed with fill material, the cover material should be relatively free of mercury.
- **Types of wetlands** – The salinity, tidal regime, and vegetation type may greatly influence methylation. Evidence from study of freshwater wetlands suggests that abundant emergent vegetation may favor mercury methylation (UC Davis 2002). This result may or may not be applicable to saltwater marshes, however.
- **Redox Control** – Mercury methylation is a process that takes place in a particular oxidation-reduction regime, and management options may be available for controlling this factor (Horne 2003).
- **Nutrient Control** – Control of nutrients entering a wetland may be an efficient way of controlling redox and the amount and type of emergent vegetation. The type and temporal and spatial variability of algae may also play a significant role in methylmercury production and biological uptake (Knapp 2002).
- **Competitive process control** – Recent research suggests that it is possible to affect the balance between different chemical forms of inorganic mercury in order to minimize the chemical form that is most readily taken up by methylating bacteria. This approach offers promise in reducing the amount of mercury that is converted to

methylmercury. This has been accomplished in pilot wetland studies by adding iron to a wetland (Horne 2003; Steding 2003).

Sediment Dredging and Disposal

Existing loss:	**- 150 kg/yr**
Projected loss:	**- 430 kg/y**
Required Actions:	**Comply with applicable dredging permits, Implement Long Term Management Strategy for the Disposal of Dredged Material (LTMS) and investigate effect of dredging activities on mercury uptake into bay food web.**

Dredging and dredged material disposal do not have an allocation because dredging activities in the bay constitute a net loss. An implementation plan is needed to assure that dredging is accomplished in a manner that does not increase bioavailability of mercury. The implementation plan for dredging and disposal activity requires continued implementation of the Dredging and Disposal of Dredged Sediment Program as described in the Basin Plan. A key component of this established program is the Long Term Management Strategy for the Disposal of Dredged Material in the San Francisco Bay Region (LTMS). The program calls for decreased reliance on in-bay disposal of dredged material and increased reliance on open ocean disposal and beneficial reuse of dredged material for wetland restorations, levee maintenance, and other upland uses. The LTMS seeks to reduce the total volume of in-bay disposal from the approximately 2,400,000 cubic yards per year (yd^3/yr) to approximately 1,000,000 yd^3/yr within about 10 years (U.S. ACE et al. 2001). At that time, the amount of mercury placed back in the bay after removal by dredging will be approximately 210 kg/yr. The amount of material removed is assumed to remain essentially the same as current, 640 kg/yr. Thus, upon full implementation of the LTMS, San Francisco Bay dredging will accomplish a net removal of about 430 kg/yr. This removal rate will diminish as sediment mercury concentrations decrease because sediment removed via dredging and out-of-bay disposal will contain less mercury over time (SFBRWQCB 2003j). Because dredging activities involve removal and transport of a large volume of mercury-containing sediment, there is a concern regarding the degree to which dredging activities may enhance mercury uptake into the bay food web. Thus, we propose requirements in the dredging permits to investigate this issue.

Risk Management

Another implementation activity is to collaborate with other California agencies to help manage the risk to consumers of mercury-contaminated fish from San Francisco Bay. In this effort, we will work with the California Office of Environmental Health Hazard Assessment and the California Department of Health Services. The risk management activities will include the following:

1. Providing fish-consumption advice to the public. Fish-consumption advisories can be effective for reducing exposure of humans to methylmercury. Existing and future monitoring data should be analyzed to determine what species of fish contain the highest amount of methylmercury. Fish consumption advisories will be prepared using such information.
2. Transferring information to the public about monitoring data and findings of environmental health professionals about hazards of eating mercury-contaminated fish. Monitoring data, combined with information from special studies, can be used to identify priority areas and target groups for outreach and education efforts, which should also communicate the health benefits of eating "clean" fish.
3. Performing special studies needed to support health-risk assessment and risk communication. These studies may include estimation of rates and patterns of fish consumption, characterization of groups with potentially high levels of exposure, identification of effective methods for communicating advice, and effectiveness evaluation of fish-consumption advisories.

Adaptive Implementation of the Mercury TMDL

Adaptive implementation of the TMDL entails applying the scientific method to the TMDL. A National Research Council review of the TMDL program strongly suggested that the key to improving the application of science in the TMDL program is to apply the scientific method to the implementation of TMDLs (NRC 2001). For a TMDL, applying the scientific method involves: taking immediate actions commensurate with available information, defining and implementing a program for refining the information on which the immediate actions are based, and a process for modifying the actions as necessary based on new information. Taking immediate actions based on currently available information allows the bay to make progress toward attaining water quality standards while we simultaneously improve our understanding of the system through research and by observing how it responds to the immediate actions.

Overview of the Adaptive Implementation of the Mercury TMDL

The adaptive implementation plan has the following features:

1. Immediate actions commensurate with available data and information. These have been described above for each source category.
2. Monitoring to assess effectiveness of immediate actions and progress toward TMDL targets.
3. Statement of Management questions, associated scientific hypotheses and a framework and schedule for addressing the management questions.
4. A process for reviewing and incorporating information obtained through the studies and monitoring into the TMDL.

At a minimum, we propose that the mercury TMDL for San Francisco Bay should be reviewed every five years to evaluate findings from monitoring, special studies and the relevant scientific literature. The 5-year reviews will be coordinated through the Regional Board's water quality Basin Planning Program, and any modifications to the TMDL elements will be incorporated into the Basin Plan. The following focusing questions will be used to conduct the reviews. Additional focusing questions will be developed in collaboration with stakeholders prior to each review.

1. Is the bay progressing toward TMDL targets as expected? If it is unclear whether there is progress, how should monitoring efforts be modified to improve our ability to detect trends? If there has not been adequate progress, how might the Regional Board implementation actions or allocations be modified?
2. What are the loads for the various source categories and how have these loads changed over time?
3. Is there new, reliable, and widely accepted scientific information that suggests modifications to targets, load allocations, or implementation actions? If so, how should the TMDL elements be modified?

Monitoring Framework

The San Francisco Bay Mercury TMDL proposes a sediment target of 0.2 ppm (dry weight), a fish tissue target of 0.2 ppm (wet weight), and an interim bird egg mercury target of 0.5 ppm (wet weight). The RMP performs the monitoring necessary to evaluate progress toward the sediment and fish tissue target, and the U.S. Fish and Wildlife Service (U.S. FWS) is collecting information on bird egg mercury concentrations necessary to evaluate progress toward the bird egg target. We anticipate that this bird egg collection and analysis will continue in the future, possibly as a regularly scheduled RMP component.

<u>Evaluation of Sediment Target</u>
The RMP collects water samples at more than 30 locations each year. We propose to evaluate progress toward the sediment mercury target by comparing it to the central tendency mercury concentration on suspended sediment particles collected at all locations in the bay. The mercury concentration on suspended sediment particles is computed as the difference between total and dissolved mercury in a water sample (at a specific location) divided by the suspended sediment concentration for that same sample.

<u>Evaluation of Fish Tissue Target</u>
The RMP conducts fish tissue sampling and analysis in San Francisco Bay every three years. The program catches and analyzes a number of different fish species from all parts of the bay. For the purpose of evaluating progress toward attainment of the fish tissue target, we propose to focus on striped bass for reasons discussed in the targets section. Striped bass are routinely caught in three separate size ranges: 45-59 centimeters (cm) (small), 60-82 cm (medium), and larger than 82 cm (large). In the past, it has been relatively easy to catch bass in the first two of these size ranges. It has been difficult to catch fish in the large size category during the sampling cruises so there is the worry that not enough could be caught in future to provide a large enough sample size. To provide sufficient data to evaluate the mercury target, we propose that at least 15 bass each in the

small and medium size ranges should be caught and analyzed individually for mercury. Because the amount of mercury in fish has shown to be proportional to the length of the fish, a common approach is to establish this relationship by plotting mercury concentration against fish length and computing the equation of the best fitting line through the data (Wiener et al., in press, SFEI 1999). Once this best linear relationship between mercury concentration and length has been established for the fish caught as part of the sampling program, the equation for the linear fit will be evaluated at 82 cm to compute the mercury concentration in fish that will be compared to the fish tissue target. The value of 82 cm was chosen because it is the upper end of the medium size category and is, thus, represents a relatively large fish in terms of what could be caught from the bay. If bass of this size are below the mercury target, it is likely that the average concentration of all bay fish consumed by sport fishers will be below the mercury fish tissue target.

<u>Evaluation of Bird Egg Target</u>
The Regional Board and CALFED (a cooperative effort state and federal agencies and local communities to improve the quality and reliability of California's water supplies and revive the San Francisco Bay-Delta ecosystem.) have contracted with U.S. FWS to conduct a pilot study of contaminant concentrations in bird eggs in San Francisco Bay. U.S. FWS will continue sampling for a couple more years. The RMP is collaborating with U.S. FWS to conduct a separate pilot study to select appropriate bird species for long term monitoring and analysis. Based on preliminary project results, candidate species include the California Clapper Rail, Caspian Tern, Least Tern, Forster’s Tern, and the non-marsh species, cormorant.

In the long term, eggs likely will be collected from cormorants and at least one of the marsh bird species listed above. We anticipate that this sampling program will be repeated once every 3 years in the future. The eggs will be collected at several locations throughout San Francisco Bay. The bird egg target of 0.5 ppm will be compared to the computed 99^{th} percentile mercury concentration of at least 40 tern (or other marsh bird species) eggs. If the bird egg mercury concentrations do not follow a normal distribution, the data should be transformed appropriately to obtain a reasonably normal distribution prior to estimation of the 99^{th} percentile. Once the percentile is computed, the result should be transformed back to the original data space before comparison to the bird egg target (e.g. if the data were squared to obtain a normal distribution, the square root of the computed percentile would be used for comparison to the target). The 99^{th} percentile is appropriate for comparison to the target because adverse effects are associated with mercury concentrations of 0.5 ppm. Therefore, very few or no eggs should have a mercury concentration higher than the bird egg target concentration.

<u>Evaluating Effectiveness of Actions Already Taken</u>
In addition to monitoring to assess progress toward targets, it is important to assess the effectiveness of actions to control mercury loads and methylation. We propose to encourage dischargers, where our permitting authority allows, to conduct effectiveness studies as they implement specific control measures so that more effective actions can be taken in the future. The range of actions to be taken is quite large so it is not possible to

describe in detail the manner in which such evaluations should be conducted. In general, however, effectiveness evaluations should document the degree to which an action results in reduced mercury loads or methylation and the cost of the action along with any information about site-specific factors relevant to applicability of the action throughout the region.

Management Questions

The purpose of this section is to identify the management questions relevant to improving our understanding of mercury sources, fate, and effects in the San Francisco Bay system such that we can better manage the mercury water quality problem. It is important to recognize that we do not need to fully understand everything about mercury in San Francisco Bay in order to make management decisions. We are focusing attention on those questions that are most relevant to solving the water quality problem. The relevant management questions deal with San Francisco Bay system processes and effects, source loads and implementation of control strategies, and TMDL targets. In the following discussion of each question, we briefly describe current hypotheses about the question, the proposed manner in which these questions would be addressed, by whom, when, why the questions are important, and how the information will be incorporated into the TMDL process.

San Francisco Bay System Processes and Effects

<u>Where is methylation occurring in the system and what are the controlling factors?</u>
This question must be addressed in order to develop management or design strategies to suppress methylation. Currently available information suggests that methylation is occurring in tidal wetlands connected to the bay and fringe mudflat areas. These areas have the necessary physical, chemical, and biological conditions required for methylation, and wetland habitats in general have been noted as likely areas of high methylation because of the maintenance of these conditions. Methylmercury may also be produced in the bay sediment and there may be some methylmercury input to the bay from tributaries.

This question can be addressed through an observational program whereby methylmercury production is measured in locations at various times along with a survey of candidate chemical, biological, and physical controlling factors. With this information in hand, options for management and design of such areas can be explored. This observational program will be accomplished through a variety of programs including RMP, grant-funded projects, and discharger-funded studies. We anticipate having a preliminary answer to this question within five years of the adoption of the TMDL. We propose to incorporate this information in a number of ways: 1) there may be more stringent measures to reduce mercury inputs to such areas, 2) we may be able to suggest management or design options for such areas aimed at controlling methylation, 3) we may be able to remove mercury from these areas if feasible.

Will erosion of mercury-laden sediment from certain regions of the bay affect water quality? The source assessment estimates that 660 kg/yr of mercury that was buried below the active layer is introduced into the system via erosion of overlying sediment. It also estimates that this process could continue for 80 years at its current rate before exhausting the excess mining legacy mercury in bay sediment. If this source continues for many decades, it will impede progress toward TMDL targets because of its magnitude. The USGS has ongoing modeling and observational studies looking into this question and we expect an improved answer within ten years. Resolution of this management question will influence estimates concerning how long it will take to reach TMDL targets, and this may influence decisions regarding frequency of certain monitoring activities as well as decisions about actions to control ongoing sources.

Are there localized methylation or bioaccumulation effects at the point of discharge?
Based on information available, we hypothesize that every molecule of mercury entering San Francisco Bay has an equal chance of becoming methylated and incorporated into biota such that there are no discernible localized impacts at the point of discharge of storm water and waste water sources. The information on which these hypotheses is based needs to be refined by measuring production of methylmercury in the vicinity of discharges to determine if the discharge itself is enhancing methylation in the receiving water. If there is evidence of localized effects at the point of discharge, we may compel dischargers to manage their discharge in such a way as to minimize methylation in receiving waters. We may also modify discharge limits to better manage localized effects. We anticipate that discharger-funded investigations will provide a preliminary answer to this question within five years of adoption of the TMDL.

What is the mercury and sediment flux out the Golden Gate?
The estimate of mercury and sediment export out the Golden Gate is estimated indirectly using information about other sources to the bay. Better estimates of sediment and mercury export may enable refinement of estimates of the time it will take for the bay to attain TMDL targets. There is active research into this question at present. We anticipate having a better estimate within 10 years of adoption of the TMDL.

What is the timeframe for recovery of the system and attainment of targets?
A simple model of the system suggests that, under the proposed allocation scheme, the bay will attain the sediment target in about 120 years. This modeling is based on the following simplifications:

- **The bay system is composed of two compartments –bay waters and the active sediment layer.** The active sediment layer is the topmost layer of sediment that is subject to routine resuspension by wind, waves, currents, and tides and most available to organisms living in the bay. This two compartment structure is a simplification of the complex structure of San Francisco Bay, but it is useful for modeling how the system might respond to load reductions.

- **The depth of the active sediment layer is 0.15 meters.** This is a simplification of a dynamic and complex process. The active sediment layer depth may vary by location, salinity, season, and a number of other factors. Since the TMDL is concerned with long-term changes and consequences, it is reasonable to reduce this process to an overall average that estimates what portion of the sediment of San Francisco Bay is likely to be resuspended into the water column.

- **Mercury below the active sediment layer is not considered in the bay system, but can enter the system when overlying sediment erodes.** Even the mercury in sediment below the active sediment layer (that below 0.15 meters) can enter the active layer through the erosion of overlying sediment. This process does not occur everywhere in the bay but, it is well documented (USGS 2001a,b).

- **The active sediment layer is completely well-mixed.** This is a reasonable assumption given that, by definition, the sediment in this layer is subject to re-suspension and mixing.

- **The mass of sediment leaving the bay balances the mass of sediment entering the bay either naturally or via dredged material disposal out of bay.** Although there are some portions of the bay that appear to be eroding, the bay as a whole is considered neither to be losing nor gaining sediment. We have no evidence that the Bay as a whole is getting shallower or deeper so the steady state assumption for sediment seems tenable.

There are already efforts underway by SFEI and USGS to help develop a more sophisticated model of sediment transport in the bay that will provide a more refined and realistic answer to the question of bay recovery within 5 years of the adoption of this TMDL.

Source Loads and Implementation of Control Strategies

<u>How much of the direct and indirect atmospheric deposition to San Francisco Bay is from controllable California sources and from Bay area sources?</u>
In order to evaluate options for controlling atmospheric deposition, we need information concerning the degree to which local sources of mercury to the atmosphere are contributing to deposition that reaches the bay directly, or indirectly through runoff. There are studies that suggest that upwind air emissions in Asia dominate the mercury concentrations in California (Steding 2002). This question is relevant because, if we find that controllable local sources contribute substantially to deposition that reaches the bay, then we may seek to control those sources. We propose to collaborate with the Bay Area Air Quality Management District to determine the contribution and controllability of local sources. We intend to improve our estimates of direct and indirect atmospheric deposition loads through a combination of monitoring and modeling studies. We anticipate having an improved estimate of atmospheric deposition and the contribution of local sources within 10 years of the adoption of the TMDL.

What is the relative bioavailability of mercury from different sources to San Francisco Bay?

Based on currently available information, we employ the simplification that mercury from all sources to the bay is equal in terms of bioavailability. Moreover, the mercury already in the system is just as bioavailable as mercury recently introduced into the system. There is emerging evidence that mercury newly-deposited from the atmosphere is more bioavailable than mercury already in the system (Benoit et al. 2003, USGS 2003) and that watershed mercury sources vary in chemical availability (CDFG 2001). Relative bioavailability was not taken into account in allocating loads because, at present, there is insufficient information on which to base allocations or to adjust allocations according to bioavailability of mercury sources. We also recognize that some mercury sources are more likely than others to enter methylating regions in and around the bay, but there is insufficient information at present to account for this potential in the allocation scheme.

Resolution of this management question is important in that it can help guide efforts to control the most bioavailable sources. If sources differ substantially in bioavailability, then load allocations could be adjusted by reducing the allocation for the most bioavailable sources. This question will be addressed through careful observational programs involving field studies and laboratory investigations – some of which will be performed in the bay and supported by CALFED and dischargers and others through a variety of ongoing research efforts looking at this issue. We anticipate having a preliminary answer to this question within five years of adoption of the TMDL.

What is the mercury load from the Central Valley Rivers?

A large source of mercury to San Francisco Bay is the amount delivered to the bay from the Sacramento and San Joaquin Rivers. It is important to have an accurate estimate of this source and track its change through time in order to predict the rate at which the bay will achieve TMDL targets. It is possible that mercury eroding from Suisun and Grizzly Bay may be confounding attempts to measure mercury loads from the Central Valley Rivers. The San Francisco Bay and Central Valley Regional Boards will work cooperatively to investigate this issue over the next 5 to 10 years. There is already work being performed through the RMP that will help resolve the question.

How much mercury is in storage in the Bay-Delta tributaries?

There may be a large amount of mercury stored in stream channels and bank deposits that may be delivered to San Francisco Bay over time. It is important to locate, quantify and characterize channel and bank storage. If it is localized, it may be possible to remove it before it reaches the bay. If we can estimate the amount and determine the factors controlling its transport downstream, we may be able to reduce loads to the bay, and we will have better information about when the bay will reach TMDL targets.

What is the relationship between mercury concentrations in sediment and mercury concentrations in the food web?

The linkage analysis proposes a linear relationship between the concentration of mercury in sediment and the concentration in fish tissue and bird eggs. In other words, if sediment mercury concentrations are reduced by a factor of two, then fish tissue and bird egg concentrations will be reduced by a factor of two. A related hypothesis is that the fraction of total mercury in the bay that is transformed to methylmercury will remain essentially constant. This hypothesis is based on the assumption that there are regions of the bay and its margins where the majority of mercury methylation takes place. Assuming that the overall fraction of total mercury transformed to methylmercury is proportional to the aerial extent of these various regions and that the spatial extent of such regions does not change substantially, then reducing mercury inputs should proportionally reduce methylmercury production. A reduction in methylmercury production will result in a reduction in the amount of mercury entering food web. In order to refine the linkage analysis, we need information about where and how mercury methylation occurs and how mercury concentration in sediment relates to mercury concentrations in the food web. These are challenging areas of research being pursued by many investigators. It is difficult to anticipate the pace of completion or specific outcomes of such studies, but we intend to incorporate any new information that helps us manage the mercury problem more effectively.

TMDL Targets

<u>Are the fish tissue, bird egg and sediment targets appropriate?</u>
Based on currently available information, striped bass is an appropriate target species because it is a fish that is popular among people who eat bay fish. There are complications with using striped bass to assess the condition of San Francisco Bay because they live only a portion of their lives in the bay. Monitoring and field investigations are needed to learn more about this species.

Based on currently available information, bird eggs represent the most sensitive wildlife endpoint, and bird eggs are distinctly more prone to hatch failure at a certain threshold level (approximately 0.5 ppm). Data on endangered bird species are currently limited in terms of the level of mercury that would cause hatch failures. U.S. FWS is currently conducting field and laboratory studies to determine how mercury impacts bird egg development. We will incorporate any new information that becomes available. We may adjust the value of the numeric target or the species we use to evaluate the target.

Conclusion

The mercury problem in San Francisco Bay may take decades to control to the point where beneficial uses are not impaired. The currently proposed regulatory strategy relies on simplifications of a complex environmental system. There is much yet to learn about mercury and how the bay will respond to control efforts. There is a lot of research underway and more planned for the future to shed light on the remaining unknown. We have an obligation to adapt the regulatory program in the future as relevant information becomes available, and we commit to do so. We also have an obligation to protect water quality by taking actions now based on the information currently available to us. To fulfill these two obligations, we propose the adaptive implementation plan of the mercury TMDL for San Francisco Bay.

Key Points

- The implementation plan has four objectives: (1) reduce total mercury loads to the bay, (2) reduce methylmercury production, (3) perform monitoring and focused studies to track progress and improve technical understanding of the system, and (4) encourage actions that address multiple contaminants.
- An adaptive implementation approach is proposed, which means taking immediate actions based on available information and defining a process by which to incorporate technical information as the plan is adapted in the future.
- The Central Valley Regional Board is developing mercury TMDLs expected to reduce mercury loads from Central Valley watersheds sufficient to ensure that sediment from Central Valley rivers eventually meets the sediment target of 0.2 ppm.
- We expect that the mercury load that is a legacy of mercury mining in the Guadalupe River watershed will be reduced to about 2 kg/yr over the next 20 years. A separate TMDL effort for this watershed will be the primary regulatory driver for actions to achieve this reduction.
- Urban storm water loads will be reduced from current 160 kg/yr to about 80 kg/yr over a course of 20 years. Compliance will be achieved through a combination of source control and targeted sediment removal and storm water treatment.
- Atmospheric deposition is thought to contribute about 27 kg/yr directly to the bay surface and about 55 kg/yr through deposition on the watershed and then conveyance to the bay. Available data suggest that this source is not easily controlled because the majority of atmospheric mercury emissions take place in Asia.
- Municipal wastewater dischargers, as a group, will be held to current mercury loads. Exceedance of proposed concentration-based triggers will compel investigation of cause and consideration of enhanced treatment.
- Existing information is insufficient to estimate loads for sources like local mines and bay margin contaminated sites. We propose to require investigation of these sites to determine their impacts and reasonable next steps to reduce loads, if necessary.
- Wetlands are not a source of new mercury, but they are important to the cycling of methylmercury in the bay. We are encouraging and supporting studies to develop ways in which wetlands can be designed and managed so as to minimize methylmercury production. If wetlands are being restored and come under our jurisdiction, we propose to require a demonstration that the project does not result in a net increase in methylmercury production.
- We will work with California agencies like the Office of Environmental Health Hazard Assessment and the Department of Health Services to manage the human health risk from consumption of mercury-contaminated fish from the bay.
- The proposed actions are commensurate with available data and information. This plan also includes monitoring to assess the effectiveness of the actions and progress toward meeting the proposed targets. The strategy calls for reviewing and incorporating into the TMDL information obtained through ongoing scientific studies and monitoring. The plan is to review this TMDL every five years through the Regional Board's water quality Basin Planning Program.

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